PUMPS

THEIR

PRINCIPLES AND CONSTRUCTION

PUMPS

THEIR

PRINCIPLES AND CONSTRUCTION

A SERIES OF LECTURES
DELIVERED AT THE POLYTECHNIC INSTITUTE
REGENT STREET, LONDON

BY

J. WRIGHT CLARKE

AUTHOR OF 'PLUMBING PRACTICE' 'LECTURES TO PLUMBERS'
'HYDRAULIC RAMS' ETC.

SECOND EDITION, REVISED

WITH SEVENTY-THREE ILLUSTRATIONS
RE-DRAWN FOR THIS EDITION

LONDON
B. T. BATSFORD, LTD., 94 HIGH HOLBORN
1919

Second Edition 1903
Reprinted March 1919

PREFACE

TO

THE SECOND EDITION

THE first edition of this little book having been exhausted and a new one called for, advantage has been taken to revise and rearrange the whole of the subject matter. The illustrations have also been re-drawn and clearer type used for the text.

In this, as in all my publications, it has been my aim to give both theoretical and practical information, suitable for masters, men, and students, at home and in the colonies, who want information on its subject. That information is needed is proved by the rather heavy correspondence asking for it, of which I am in constant receipt.

I desire to thank Mr. Batsford for the kindly interest he has taken in the book, and also for the advice and assistance he has given in the re-arrangement of the contents.

J. WRIGHT CLARKE.

LONDON, *September* 1903.

CONTENTS

LIST OF ILLUSTRATIONS

PUMPS:

THEIR PRINCIPLES AND CONSTRUCTION

CHAPTER I

The Construction of Jack Pumps

The common leaden 'jack pump' is much used, and its parts and construction will be first described. Fig. 1 is a section in which G is the 'suction' pipe, or the pipe that extends from the pump to below the water surface in the well or underground reservoir. H is the tail valve or 'sucker,' as it is usually called, made of elm. An enlarged sectional drawing of this is shown in Fig. 5. In the latter figure, I is a lead 'clack,' generally cast by the plumber in a 'clack mould,' with a 'tang' for passing through the piece of leather, J, and riveting on the other side. The leather is then nailed to the sucker at K. In Fig. 1, L is the pump barrel, which is sometimes made out of a very strong piece of lead pipe, although a great many barrels are cast in moulds. In some parts of the country plumbers make the barrels themselves out of plate lead, $\frac{3}{8}$ in. to $\frac{1}{2}$ in. thick, and 'ladle burn' the seams on the sides, as was described in my book 'Plumbing Practice.' The head, M is only

used on cast lead pumps. When the plumber makes the barrel himself it is usual for him to make it long enough above the nozzle N, to answer the purpose of the head for preventing the water overflowing the top when the nozzle does not take it away quickly enough. The 'bucket' O is made of elm. An enlarged section of a bucket is shown by Fig. 2. A piece of leather, P, is folded round the bucket and nailed on the bottom edge. This is sometimes called the 'bucket-leather' and sometimes the 'cup-leather.' In the centre of the bucket another clack and leather is fixed as was described for the sucker. The bucket is fastened on to the rod O, made of wrought iron and having a flange, R, upon it, by means of a 'split key,' S, and an iron washer to prevent the key cutting into the wood.

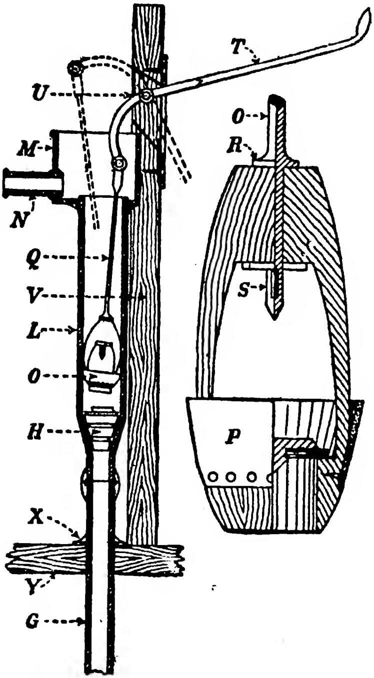

FIG. 1. FIG. 2.

The pump handle, T, Fig. 1, is made of wrought, although a great many are now made of malleable-cast, iron. The handle works on a pivot or 'pin,' U, in the wooden plank V. The plank is mounted on a piece of oak, fixed over or at one side of the well, with bracing pieces to keep it steady and prevent it rocking. The pin U is sometimes fixed by a screw, through a flattened head which projects through the side of the wood plank.

Fig. 3 shows this pin and also the evil result of fixing it too rigidly. By frequent usage the part at W is worn away, and an equal amount of friction in the hole or eye through the handle results in the latter also being much worn. If the pin is not fixed it revolves by the action of the handle, and in this case the hole through the plank, instead of the bolt, is worn away. To prevent either of these evils occurring, the hole in the plank should have brass or gun-metal 'bushes' inserted for the pin to revolve in, and a capping piece should be fixed over the end of the bolt to prevent it working out of the plank.

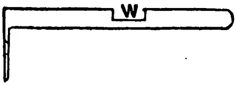

FIG. 3.

In Fig. 1, it will be noticed that the pump head is notched into the plank. This should always be done, or other means taken, to prevent an up and down motion of the barrel in unison with the handle when the pump is being worked. Neglect of this precaution results in the suction pipe becoming detached from the pump, or in a fracture through which air can enter and thus prevent a vacuum being formed inside the barrel, and by reaons of which no water can be raised.

If water refuses to come when the pump is worked, although the distance above the well water is not too great, there is cause for suspecting that there is a hole in the suction pipe. To find if there is such a hole, the pump handle should be worked for a few minutes and then the ear placed close to, or touching, the nozzle. If a slight 'sissing' noise is heard it will generally be found that there is either a hole in the pipe or the pipe is cracked.

Another reason of the suction pipe leaking is because of careless or improper fixing, so that the whole weight of the pipe is hanging on to the pump. A flange soldered on as shown at X, Fig. 1, helps to support the weight of both the suction pipe and the pump, the base Y being either a piece of oak plank, or a stone slab, perforated for the pipe to pass through. Where the vertical length of the suction pipe is several feet, similar planks extending across the well, or perforated stone corbels built into the steining, should be fixed, and lead flanges soldered on to the pipe similar to that shown at X.

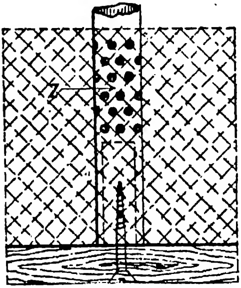

FIG. 4.

As a further support for the pipe some plumbers will insert a wooden plug in the bottom end and nail on a piece of board, as shown by Fig. 4, to rest on the bottom of the well. This plug and board also helps to keep the pipe from sinking into the mud, which would be carried up

with the water and clog the sucker and bucket clacks.

When the well is sunk in sandy or other loose soil the perforations, Z, Fig. 4, should be kept up some distance from the bottom. When the pump is to be used for sewage and similar liquids it then becomes necessary to have a strainer, as shown by crossed lines, or to fix the pipe in a second chamber into which the liquid matter only is allowed to flow or pass.

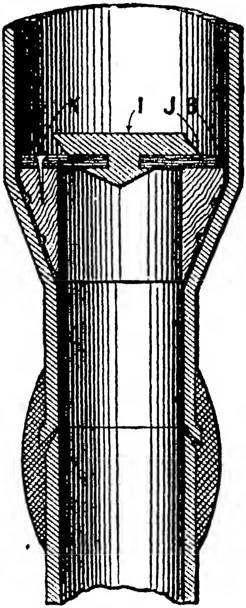

FIG. 5.

There are several details in putting a pump together ready for fixing that require consideration, and these will now be dealt with. Very rarely indeed is the soldered joint to the tail end of the pump properly socketed. Fig. 5 shows how it should be done. It will be noticed that the suction has a male, and the tail piece a female, end. Whenever it is necessary to repair or renew the sucker the rod shown by Fig. 6 has to be used for pulling the sucker out. The end of the rod has a screwed point which is forced into the lead clack for pulling the latter off the sucker. Or an iron wire with a bent end is passed down the barrel,

the bent end worked under the edge of the clack leather, and the latter held open until the sucker rod has been passed through and the harpoon end placed under the bottom edge of the sucker ready for dragging it out. Should the rod be lowered too far, and the soldered joint socketed the opposite way to that shown in the figure, the harpoon end would catch on the edge of the lead pipe, and the latter would be injured and torn. With the joint as shown in the figure this cannot occur.

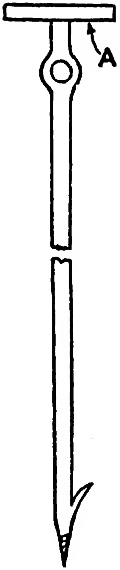

FIG. 6.

To fix the wood sucker hard hemp (not soft tow) is first wound round the outside of the sucker, and melted tallow is then poured out of a ladle on to the hemp. The sucker is held on the point of the sucker rod, which is screwed into the lead clack just sufficient to hold it, and then lowered into its position in the barrel. The rod is then unscrewed, taken out, reversed, and the sucker driven down by the flat head, A, of the rod, Fig. 6. When necessary to take out the sucker for repairs some plumbers will first pour boiling water into the pump, others will burn straw or paper, or surround the outside of the pump tail with hot water rags. The applied heat remelts the tallow, and also slightly expands the lead, so that lesser force has to be used to pull the sucker out.

The hemp should be wound on the sucker very tight, and kept not less than half an inch below

the top edge. If loosely done, too much used, or wound too high up, some portion of the hemp will project above the sucker, get beneath the clack leather, and prevent it closing properly. The clack leather should not be too large, and it is an advantage to allow for a probable stretching, otherwise the edge will rub against the side of the barrel. A clear space should be left, as shown at B, Fig. 5.

The bucket should be well soaked in water for an hour or two before being leathered, otherwise it will split when nailing on either the outside or the clack leather. The leather is generally of the kind used for boot soles, and called 'water-dressed,' although some plumbers prefer 'oil-dressed' for lead jack pumps. A strip about ½ in. longer than the girth of the bucket, and from 1½ in. to 2 in. wide, according to the size of the pump, is well soaked in water, and then the ends and one edge chamfered on the rough or flesh side. The leather is then nailed on to the bucket, as shown at P, Fig. 2, small copper nails being used, and care taken that the bottom edge of the leather does not project above the rebate cut in the wood. The clack should be fixed before the cup leather is nailed on and freedom at the edges allowed for, as described for the sucker clack.

The buckets are generally bought, although some country plumbers who have lathes will turn them themselves, and bore a small hole through them for fixing on the rod. To enlarge the hole to the exact size, the end of the rod is made red hot and then forced through the hole, through which it burns its way. The burning should be done very quickly and the bucket and rod im-

mediately plunged into water, otherwise the hole would be burnt too large, and the bucket could not be firmly fixed on the rod. Iron washers and a 'split key,' as shown at S, Fig. 2, are used for fixing the bucket on to the rod.

Great care has to be taken in mounting the bucket rod and pump handle. If the pin in the plank is too high up, so much water is not raised, owing to the shortness of the stroke, and the bucket is drawn partly out of the top of the barrel. If the pin is too low down the bottom of the bucket knocks on the top of the sucker at each upward stroke of the handle. Another evil in the latter case is the bending of the bucket rod, or the wearing and distorting of the inside of the top of the pump barrel by the rocking of the rod, as shown by dotted lines, Fig. 1, at each up and down stroke of the handle.

When preparing a square cast lead head for soldering on the barrel and nozzle, the holes in the lead are best made by burning, or melting, through with a red hot plumber's iron. This does not distort the lead so much as when the holes are cut with a chipping knife and hammer. With a cast lead pump the end of the nozzle is soldered on the inside of the head, and as near the bottom as possible. The barrel joint is wiped on the outside of the head. The end of the barrel should project about $\frac{1}{2}$ in. to $\frac{3}{4}$ in. above the bottom of the head, and thus lessen the risk of anything falling into the barrel and getting jambed between the bucket and sides.

All jack pumps with open tops should be encased with woodwork to prevent anything falling in and injuring any parts. No doubt many readers

can recall similar experiences to the writer's, where mischievous children have stood at a distance and pitched pebbles into the pump-head, or shied them into the nozzle, and can realise the difficulty of getting them out again, especially after an attempt has been made to work the pump.

The proper diameter for the suction pipe is usually considered as being half that of the barrel. That is to say, a 4 in. pump should have a 2 in. suction, and a 3 in. pump a 1½ in. suction. These sizes have become established by practice. This matter and the principles of the action of a pump will be now considered.

CHAPTER II

Atmospheric Pressure and the Action of Pumps

To thoroughly understand the action of a pump it will be necessary to first explain what 'atmospheric pressure' means, as this influence has a great deal to do with the subject.

When reading the weather reports, as published in newspapers, we frequently find the statement, 'Barometer 30·0 in. over the Spanish Peninsula; 29·9 in. in Sweden; 29·78 in. at Brixton;' and so on for other parts of the world or our own country, the figures varying from day to day and almost hour to hour. Accompanying these reports is a paragraph stating, 'The barometrical readings are corrected to sea level, and reduced to 32 degs. Fahr.'

The atmosphere surrounding our earth presses, we may say almost like water, in all directions. As we leave the earth and get higher up into the air, as when mountain climbing or ballooning, the pressure is reduced, and as we go down, into a mine for instance, it is increased. The height of mountains, or balloons when soaring, can be found by the use of a barometric tube. As the air is of different densities at different heights, for the purpose of making calculations it is necessary that

some datum should be fixed to work from. As we live on the surface of the earth it is found to be convenient to have some level as near as possible to that in which we live, and this, fixed upon by scientists, is the 'sea level.'

Heat has an influence on atmospheric pressure. Heated air is expanded air. A cubic foot of air at a temperature of 32 degs. Fahr. weighs ·0807 lb., at 22 degs. ·0824 lb., and at 42 degs. ·0791 lb. Hence the necessity of taking note of the temperature when making calculations as to atmospheric pressure. The datum for this is 32 degs. Fahr.

Old pump hands no doubt have noticed that on some days a pump fixed just within the limits will deliver a fair amount of water, and on other days will not deliver any. This has arisen from the variations in atmospheric temperature and pressure.

A barometer is an instrument by which atmospheric pressure is measured, and consists of a tube having one end sealed and made air-tight, and the other end bent upwards as Fig. 7. The length of the longest part is about 36 in., and the short one 4 in. This tube is filled with mercury, care being taken to get out all the air, otherwise it will not act properly. When the tube is filled and stood upright, as shown in the figure, an empty space, or vacuum, will be left at the top, B, and some portion of the mercury will overflow the short end C. A further small quantity being emptied out, and a float placed in the short open end of the tube with a thin cord attached, and passed over a pulley wheel, D, and with a small counterbalance weight at E, the whole constitutes an ordinary barometer. The dial or pointer moves round as the air pressure

varies, and the mercury is pushed up or lowered down in the vacuum at B.

The instrument is sometimes called a 'weather glass,' and the face, or dial plate, which is not shown in the figure, is marked with terms denoting the state of the weather. But it is only a weigher

FIG. 7.

FIG. 8.

FIG. 9.

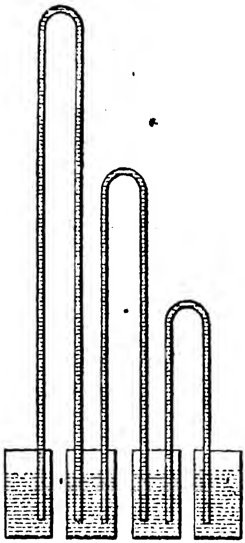

FIG. 10.

of the density of the air. As variations in the latter usually precede a change in the state of the weather, the barometer is a valuable aid to foretelling what form those changes will take.

If the measured distance between the exposed surface of the mercury in the short leg and that in

the vacuum end of the tube is 30 in., we then say the barometer reads that pressure.

Anyone can make an instrument for demonstrating atmospheric pressure. Buy a strong glass tube with about $\frac{1}{8}$ in. bore and 34 in. long, and seal one end by the aid of a flame and blow-pipe. Also buy a small glass jar, about the size of those supplied with cheap bird-cages, and one or two pounds of mercury. Stand the tube on its closed end, in a basin or saucer to catch any spilled mercury, and fill the tube quite full with mercury. Pour the remainder of the mercury into the glass cup or jar, place a finger over the open end of the filled tube, invert it and plunge it into the jar. On removing the finger some of the mercury will pass out of the tube and leave a vacuum in the top. On measuring it will generally be found that the distance between the surfaces of the mercury in the vacuum and in the open jar will be about 30 inches. But this will be more or less according to the atmospheric pressure at time of the experiment.

If an india-rubber bung with a hole through it is placed on the tube, and the jar and immersed end of the tube is lowered into a wide-mouthed bottle, as shown by Fig. 8, the height of the column of mercury can be varied by either adding to or taking from the ordinary atmospheric pressure. Through a second hole in the bung pass a piece of glass tube having a stop-cock, or a piece of india-rubber tubing with a brass spring clip fitted instead of the cock. If the bung fits quite air-tight, and a person blows through the small tube into the bottle, the atmospheric pressure inside will be increased, and some of the mercury will be

forced up the tube into the empty space at the top end. If, on the contrary, some of the air is sucked out of the bottle, the pressure will be reduced, more mercury will run into the cup, and the vacuum space at the top end of the tube will be increased. Blowing into the tube has the same effect as if the apparatus had been lowered down a deep mine or some position considerably below the level of the sea. Exhausting the air produces the same result as if the tube, &c., had been carried up a high mountain. By this appliance we find that, measured from our usual datum, the pressure of the air will support a column of mercury, in a vacuum, to a height of about 30 in.

If the pressure of the atmosphere is taken at sea level, the temperature at 32 degs. as before stated, and we find it will support a column of mercury at the above height, we then know that the air pressure is equal to 14·7 lbs. on the square inch. To find this we multiply the weight of 1 cubic inch of mercury, which is ·4903 lb., by the height of the column in the vacuum tube, which is 30 in., or $\cdot 4903 \times 30 = 14\cdot 7090$, or 14·7 lbs. in round numbers.

If a tube about 35 ft. or 36 ft. long was sealed at one end, similar to the mercury tube, and then laid in a long trough of water, the open end of the tube being slightly raised for the air to escape and water to take its place, and then stood upright without taking the open end out of the water, we should find that a vacuum would be left at the top of the tube similar to the one that was filled with mercury. But in this case, roughly speaking, the measurements would be in feet instead of inches. An inch of mercury is equal to 13·6 in. of water.

This is a difficult experiment to perform in a class-room owing to the unwieldy length of the tube. But by another illustration and the aid of a small tube, the relative weights of mercury and water can be shown.

Take a piece of $\frac{1}{4}$ in. or $\frac{3}{8}$ in. glass tube, about 5 ft. or 4 ft. long, and bend one end, about 5 in. or 6 in., as shown by Fig. 9, and stand on the bent end. Pour mercury into the tube to a height of about 3 in. It will be this height on both sides of the bend, as the ends are open and the air can escape as the mercury is poured into the tube. Now pour water into the long leg until it is filled, or nearly so. On looking at the mercury it will be found to have risen in the short leg and lowered on the opposite side, as shown by the dark part in the figure, and by measurement the difference in height will be found to be about 3 in. I said about, because it is difficult to take an exact measurement owing to the refraction of the glass and the surfaces of the mercury not being even, but are raised, or convex, in the centre. To find if the 3 in. is correct, measure the height of the column of water above the mercury and divide the height by the specific gravity, or relative weight of the mercury, which is 13·596, or say 13·6, at a temperature of about 60 degs. F. Assuming the water measures 3 ft. 4 in. in height, then 3 ft. 4 in. or 40 in. $\div$ 13·6 $=$ 2·94 in., as being the exact difference in the level of the two columns of mercury in the bent tube.

The experiments have shown that:—

(*a*) Under ordinary conditions the atmospheric pressure will support a column of mercury in a vacuum at a height of 30 in.

(*b*) One inch of mercury exerts a pressure of 13·6 times that of an equal bulk of water, and

(*c*) The pressure of the atmosphere is equal to 14·7 lbs. on the square inch.

With this knowledge it is easy to calculate the depth from which a pump will raise water, and the rule is as follows :—

Divide the atmospheric pressure in lbs. per square inch by the weight of 1 square inch of water 1 ft. high. In a previous lecture[1] the latter was found to be ·434 lb. Then $14·7 \div ·434 = 33·87$ ft., or 33 ft. $10\frac{1}{2}$ in. nearly.

This distance measured from the top of the valve in the pump bucket to the surface of the water in the well is the extreme height the water will rise in the suction pipe when the air has been drawn out, no matter how long the pipe may be. At a height of 33 ft. $10\frac{1}{2}$ in. the weight of water in the suction pipe and the atmospheric pressure on the outside water in the well are in a state of equilibrium. Under these conditions no water would be delivered by the pump. If the distance is measured from the sucker clack instead of from the bucket, no useful work would be done by the pump as the water would not be pushed any higher than the sucker clack.

When pumping, it is frequently found that the surface of the water in the well subsides as the water is drawn up, hence a pump may answer satisfactorily for a short time and then 'give out,' as it is called, although there may be plenty of water at a lower level. After an interval of time the pump will again do what is required, and after using again give out. This is because the water

[1] *Lectures to Plumbers*, Second Series. Batsford, 1903.

surface exceeds the theoretical distance below the bucket.

It is necessary to again remind the student that temperature and atmospheric pressure have to be considered, and that 1 in. of variation in a mercury barometer is equal to about 13½ in. in a water barometer. To find the maximum working height of a pump, add together the amounts that should be allowed for probable contingencies, and deduct the total from the theoretical height, as given above, thus :—

	ft.	in.
Subsidence of water in the well, say .	3	0
Variation in barometer = 1 in. . .	1	1½
Length of bucket stroke		9
Which gives a total of . .	4	10½

which deducted from the 33 ft. 10½ in., leaves 29 ft. On no account should a pump be fixed with its bucket more than the latter distance above the water it is to raise. In everyday practice it is as well to reduce the distance to 25 ft. or less.

The above distance would be varied for hot and sea waters, the former being lighter and the latter heavier than ordinary or spring water. Spring water at 62 degs. Fahr. weighs 62·32 lbs. per cubic foot, but at 212 degs., or boiling point, it weighs only 59·82 lbs. By working this out as in previous problems, we find that the theoretical height to which boiling water will be pushed when the mercury barometer stands at 30 in. is nearly 34 ft., as against 33 ft. 10½ in. with the cold water.

But here another detail has to be considered. Water boils at 212 degs. in an open vessel, when it may be said to be under a pressure of one

atmosphere. If this pressure is reduced the boiling point is at a much lower temperature. Water heated in a flask or vessel to 180 degs., and then placed under the receiver of an air pump, will boil violently, and large quantities of steam will be given off when the air pressure has been reduced to half an atmosphere. Even with a defective air pump, the writer has found water to boil as low as 120 degs. Water in a suction pipe of a pump will boil at a very low temperature, and give off large volumes of steam. This interferes very much with the quantity of hot water raised by a pump.

If the specific gravity of sea water is taken as 1·027, by calculation we find that a cubic foot weighs 63·98 lbs. If we divide this by 144 we have ·4443 lb. as the pressure on a square inch for one foot in height. And $14{\cdot}7 \div {\cdot}4443 = 33{\cdot}08$, or say 33 ft., this being the theoretical height to which sea water of ordinary density would rise, in the suction pipe of a pump, above the level of the water surface.

We now know the limit from which water can be raised by a pump to its own height.

ACTION OF A SIPHON

It may here be considered convenient to refer to the action and limits of a siphon. If a tube is bent to the form of a ∩ it will form what is commonly known as a siphon. If the tube is filled with, and one end is placed in a vessel containing, water the contents of the vessel will run out of the outer tube until the vessel is emptied and the inner end of the tube is exposed so that air can enter, always provided that the outside leg was

the longer of the two. If the bent tube was filled and then the two ends immersed in cups or other vessels, filled with water as shown by Fig. 10, the contents of the vessels would stand at the same level, and if water was dipped out of one and poured into the other, it would at once run back until the levels were again the same. And this would act with tubes of any size and any length within the limits that have been explained in connection with a pump suction.

A row of water vessels all connected by means of siphons which were charged with water would remain filled to the same level, provided they all stood on the same horizontal line. If one vessel is raised or lowered, the contents will be siphoned out in the former case and increased in the latter. To test this with a water siphon to a height of 33 ft. 10½ in. would be a troublesome matter, and would require an arrangement of stop-cocks for filling the siphon and starting the action. But, here again, mercury can be used instead of water. If the tubes and vessels shown by Fig. 10 were charged with mercury, the same results would obtain as with water if the length of the tubes was less than 30 in., measured from the surface of the contents of the vessels. But if this height was increased only 1 in., or if the atmospheric pressure, as registered by a barometer, was 29 in. instead of 30 in., the siphon would cease to act, and, if made of glass, an empty space, or vacuum, would be seen inside the top. We thus find that pumps and siphons are bounded by equal limits as to the vertical height at which they will work.

In previous remarks the word 'push' has been made use of, and it now becomes necessary to

explain the meaning or application of that term. With junior students there is an impression that the water in a pump suction is dragged or lifted up, when the handle is worked, much in the same manner as if the water was a solid body which had sufficient tenacity to resist being pulled asunder. Water does cling together it is true, but the cohesion is so very low that there is little or no difficulty in separating portions of it. When the handle of a pump is first worked the bucket is perhaps several feet away from and is not in contact with the water in any way. When a pump is first fixed there is air inside the barrel and also in the suction pipe. This air exerts, as we have already found, a pressure of 14·7 lbs. on each square inch of surface exposed to it. And this amount of pressure is exerted on the surface of the water inside the pipe as well as on that outside, or, as we usually express it, the inside and outside pressures are in a state of equilibrium. When the pump handle is raised and then lowered the bucket first descends and then ascends. When ascending it lifts up the air pressing on its upper side, and in doing this takes off the pressure on the water inside the suction pipe. The internal and external air pressures being unequal, that outside, on the surface of the water in the well, being the greater, pushes the water up into the space where the atmosphere is no longer exerting any pressure. After the first stroke of the pump, when some of the air has been exhausted out of the suction, the remainder, being no longer pressed closely together by the weight above it, expands and becomes less dense. The handle being again worked more air is lifted out, the remainder is more rarefied, and, by repeating

the operation, becomes so thin as to approach what is generally termed a vacuum in the containing space. External air presses or pushes the well water into this space, and the working of the bucket then lifts some of the water out, leaving a vacuum behind, which is again filled as before. The water above the bucket is lifted out, but that below is pushed up by the atmosphere as above explained.

And so with a siphon. But in this case the tube has to be first filled with water before placing in position, or the air has to be exhausted by some means until none is left, after placing in position. When the siphon is charged, the water in the outside, or long leg, is heaviest and falls down, and more is pushed up the inner leg by the atmospheric pressure on the surface of that in the vessel. And this goes on for so long as any water remains in the vessel or until the inner end of the siphon is exposed and air can pass in. To restart the action this air must again be exhausted out of the siphon.

CHAPTER III

PUMP HANDLES

To work a pump a certain amount of force or power must be exerted. With a jack pump the power is applied by means of a lever, or as we call it the handle. The advantage of this mechanical

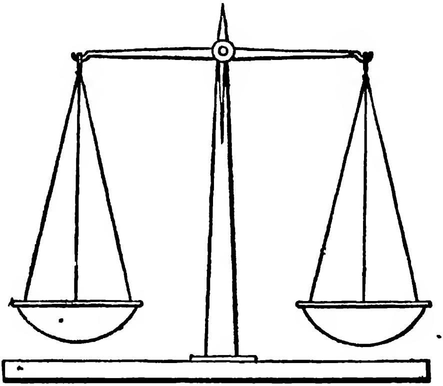

FIG. 11.

appliance can be explained by studying a pair of beam scales, as shown by Fig. 11. Assuming that the scales are exactly balanced and are hung on the extremities of the arms at the same distance

from the pillar, or fulcrum, a weight of ten or any number of pounds placed in one pan would balance an equal weight placed in the other pan. But by this there would be no gain of power. Ten pounds of applied power only produces ten pounds of work done by lifting, as the power and work are balanced and the two move through the same distance or space in the same time. If we were to move the pillar nearer to one of the pans and assume that they were both adjusted so as to still balance each other, then a large weight in one pan would be necessary to balance a small weight in the other pan. And a small weight at

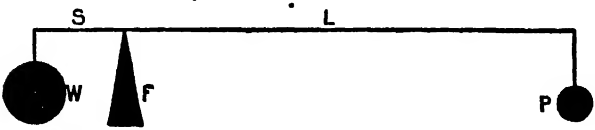

FIG. 12

the long end of a lever would support a heavier weight at the short end. Assume that Fig. 12 is a balanced lever supported on a centre or fulcrum at F. W is a weight to be lifted, and P is the weight or power to be applied to lift W.

The formula for working lever problems is

$$P = \frac{W \times S}{L}$$

In which W = the weight.
S = the length of the short arm.
L = the length of the long arm.
P = the power to be exerted.

As an example :—Let $W = 100$ lbs.
$S = 6$ inches
$L = 30$ inches

Then $P = \frac{100 \times 6}{30} = 20$ lbs., which would just balance W.

Or, if another example is taken to find the length of the long arm when the other particulars are given:

Let $W = 500$ lbs
$S = 12$ inches
$P = 40$ lbs.

The formula for this becomes

$$L = \frac{W \times S}{P}.$$

Then

$$L = \frac{500 \times 12}{40} = 150 \text{ in.} =$$

the length of the long arm to balance W.

In the case of a jack pump the power to work it is derived from the man who works the lever or handle. The man has to exert his power at arm's length, and he cannot do so much work as he could if the lever was placed in a more favourable position, or where he could stand over the handle and push and pull it with least fatigue to himself. When using an ordinary jack pump the man has to first raise the handle, and, if the latter is properly balanced, this does not require much exertion. But when pulling it down he must use sufficient force to raise the load hanging on to the bucket at the other end. For continuous work at arm's

length an average man cannot press down with a power exceeding about 20 lbs. of weight, and this may be taken as a basis for making calculations. In pump problems this power would be looked upon as a constant P.

To find the weight, that is, the column of water on and under the bucket to be raised when pumping, the rule is :—Diameter of the cross section of the pump barrel in inches squared × the distance from the surface of the water in the well to the surface of that in the pump in feet × ·34.

The answer will be in pounds.

Example :—Assume a 3 in. pump and 20 ft. as the height of the column of water to be lifted.

Then 3^2 × ·34 lb. × 20 ft. = 61 1-5th lbs. In this rule ·34 lb. is the weight of water contained in 1 ft. of 1 in. pipe, and is found by dividing 62·5 lbs. by 144 in. and × ·7854. If the length of the bucket end of the handle is 6 in., measured from the centre of the plank pin to the centre of the bolt of the bucket rod, we can then find the length of the handle necessary for a man to use the pump with useful effect.

Then, for this case, using the same formula as for the lever, the length of the pump handle should be not less than

$$\frac{61 \text{ lbs.} \times 6 \text{ in.}}{20 \text{ lbs.}} = \frac{366}{20} = 18\tfrac{1}{4} \text{ in.}$$

This length would not allow space for the man to grip with both hands at the extreme end of the handle, and in addition there would be no preponderance of power over load. To make an allowance for this at least 6 in. should be added on to

the length of the handle, thus making it 24 in. long.

Taking another example with a 25 ft. length of column and a 4 in. pump, then $4^2 \times \cdot 34$ lb. $\times$ 25 ft. = 136 lbs. to be lifted. If the length of the short arm is 7 in. we then have

$$\frac{136 \times 7}{20} = \frac{952}{20} = 47 \cdot 6 \text{ in.}$$

as the net length of handle to which 6 in. should be added for reasons above given.

The total length of about 4 ft. 6 in. would make the handle unwieldy and difficult for a man of ordinary stature to work. Neither could he reach high enough to get the full length of stroke, which should be about 12 in, in the barrel of the pump. To do this his hands would have to travel a distance of over 7 ft. If the handle was 3 ft. long his hands would pass through 5 ft. 5 in. of space, and if 2 ft. 6 in. long, the distance would be 4 ft. 5 in. Fig. 13 is drawn to scale to explain this.

To work the 4 in. pump and get the full effect a shorter handle could be fixed and two men employed if for continuous work. One man would perhaps be able to get useful effect, but for a short time only.

In these calculations it was assumed that the handle just balanced the short arm and the weight of the bucket and rod, and no allowance was made for friction of the bucket leather against the inside of the barrel. This should be allowed for. When the bucket is going downwards the friction is very small, but when the bucket is rising the friction is considerable, as the leather is pushed or pressed

closely to the sides of the pump by the weight of the water. As *friction is proportional to load*, the

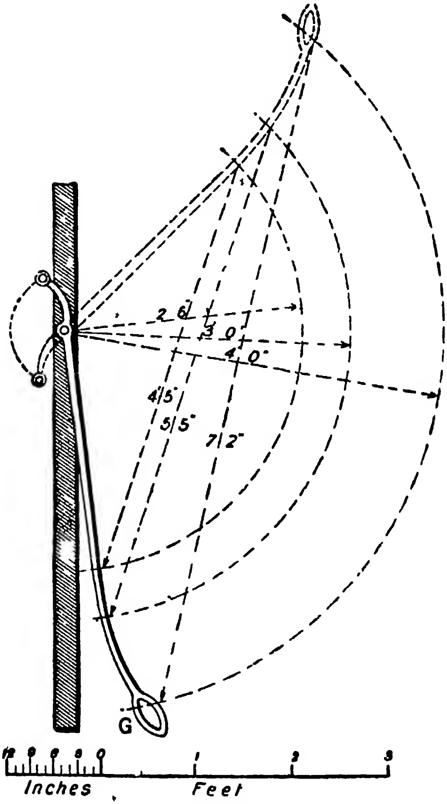

FIG. 13.

greater the depth from which the water is being raised the greater the friction. No fixed rule can

be given that would suit all conditions, but it may be assumed that two pounds on the end of the handle would be an average allowance to overcome the additional load in the form of friction.

Mention has been made that, when properly balanced, not much exertion is required to raise the handle. But if the handle was made heavier than the bucket and rod more power would have to be exerted when raising the handle, but less power when pulling the handle down. Advantage can be taken of this to lighten the man's labour when pumping. Assuming that the end of the handle is swelled out to the form of a bulb as at G, Fig. 13, and that this and the handle itself weighs ten pounds more than the weight of the bucket and rod; if from this the two pounds allowed for the bucket friction is deducted, eight pounds remain, and this weight is equal to adding that amount of power to the man's arms when pulling down.

To show the advantage of this again take the problem of the 4 in. pump with the 25 ft. column of water.

Then $\frac{136 \times 7}{28} = 34$ in. as length of handle,

to which should be added a few inches for gripping by the hands as before. On referring to Fig. 13 it will be seen that the man's hands would have to travel a distance of about 5 ft. 5 in. Although power is gained the task is still too heavy for one man to work at continuously or for any length of time. The labour could be still further reduced by shortening the distance the bucket travels. This would be done by reducing the

length of the short arm of the handle. But although the man's actual efforts would be less they would have to be sustained for a longer time if a given quantity of water had to be raised.

If the short arm was 6 in. long, instead of 7 in., the long arm would have a net length of:

$$\frac{136 \times 6}{28} = \frac{204}{7} = 29 \text{ 1-7th in.}$$

to which add 6 in. as before = 35 in. On referring to Fig. 13 it will be seen that the hands travel a distance of 4 ft. 5 in., which is a great saving on the preceding example.

It may have occurred to readers that the weight of water resting on the bucket and contained in the suction pipe has been assumed to be the same as the contents of a pipe equal in area to the full size of the barrel. In other words that the suction pipe is the same diameter as the pump barrel. In practice, the diameter of the suction is usually half that of the barrel. In a 4 in. barrel and 2 in. suction the contents are as 4 is to 1. Consequently the water in one foot of the pump weighs four times as much as the water contained in one foot of the pipe. But it is not a question of weight of water, but of atmospheric pressure. When raising the bucket the water above it is lifted, and also a column of air of the same diameter as the barrel. And the weight of this is equal to a column of water of equal diameter with the pump, and of a length equal to the distance from the water in the well.

If the suction and pump are of equal diameters the latter will work easier, although there is a

larger quantity of water in the former. By reducing the size of the suction pipe the work is made harder for the operator. It may here be stated that *friction increases as the square of the velocity.* If a 4 in. pump has a 12 in. stroke, is worked at the rate of 30 strokes per minute, and the up and down travel of the bucket take equal times, the water is then moving at the rate of one foot each alternate second. If the suction was of equal area to the barrel the water would travel with the same velocity in both. But if a smaller suction pipe is used, then the water in it must travel at a higher speed. With a 2 in. suction the speed would be four times that in the 4 in. barrel. And the square of 4 = 16, or the number of times that the friction would be increased over what it would be if the pump and suction pipe were of the same diameter.

The writer has seen jack pumps fitted with suction pipes much too small; for instance, 3 in. with 1 in., and 4 in. with 1½ in. suctions. This is always a false economy, as, although there may be a slight saving in the first cost of materials, extra effort is required to work such pumps, and wear and tear of the human frame should always be considered when designing such appliances. At all events, it is not necessary to waste strength on unproductive results. The diameter of the suction pipe should never be less than half that of the barrel, but two-thirds the size would lessen the labour expended in overcoming friction.

CHAPTER IV

THE USE OF AIR VESSELS ON SUCTION PIPES

INERTIA of water is another factor which should be considered in pump work. Like all inanimate bodies, water has no power in itself to move or to stop when in motion. When pulling down a pump handle, the first part of the labour is expended in overcoming the inertia and putting the water in motion; the rest of the stroke, after movement has been started, being much easier. With ordinary jack pumps this extra effort is required at each stroke. When the suction pipes are very short this does not much matter, but when they are very long it will economise labour if an air vessel is fixed, as shown by Fig. 14, when the

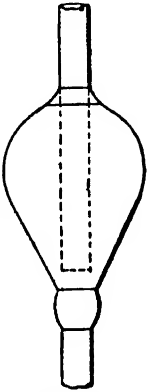

FIG. 14.

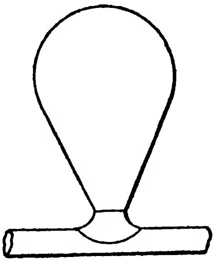

FIG. 15.

pipe is vertical, or as Fig. 15 when the pipe is horizontal.

To explain the advantages of air vessels, it must first be taken that air is elastic and can be compressed into a smaller space or expanded to fill a larger space. In either case the air retains its physical or natural property of returning to its original density when opportunity offers. The air in a vessel attached to the suction pipe of a pump is rarefied or made thinner by reason of its being between two forces, one force being the weight of water in the pipe which is drawn down in common with all bodies by the attraction of terrestrial gravity —the opposite force being the pump bucket by which the air in the first instance, and water afterwards, is lifted out of the barrel as fast as it is pushed up from the well.

To make the action clear an experiment can be tried with a piece of flexible india-rubber or a spiral spring. If one end is fixed to a beam, or similar support, and a weight is suspended from the other end the spring will elongate or stretch. A gentle pull given to the weighted end would still further stretch the spring, and on releasing the pull, the extra tension being removed, the weight would rise to its first position.

After starting the pump and exhausting the air out of the suction pipe, the air in the vessel is stretched or expanded to a certain degree of rarefaction, and remains so, although the pipe is full of water, until the handle is again operated, when it is still further expanded. As soon as the extra tension is removed the air in the vessel begins to return to its previous state of tension, and for this the water must rise in the suction pipe

and partly fill the air vessel. During the time the water is rising in the suction pipe the pump handle is being raised for the next stroke, so that when it is pulled down, the water in the suction does not require so much effort to put it in motion at the commencement of the downward stroke.

The best position for the vessel to be fixed in the suction pipe is as close to the tail valve of the pump as may be convenient.

The advantage of an air vessel is particularly noticeable where a pump is fixed a considerable distance from the well. The writer had a case a few years ago where a pump in a rose garden was used for raising liquid sewage from an underground tank distant about 100 yards, the vertical height to which it was raised being about 15 ft. An air vessel made the pump much easier to work.

We have now dealt with (*a*) a jack pump and its parts and construction, (*b*) the power to work it, (*c*) how to calculate the length of the handle, (*d*) the size of suction pipe, and (*e*) the advantage of an air vessel when the suction is very long. We may now consider the useful effect to be got out of a pump.

THE USEFUL EFFECT OF A PUMP

The theoretical quantity of water raised in a given time is found by multiplying the squared diameter of the barrel in inches by the length of stroke, by the rate or speed of working, and by ·034. Example, a 3 in. pump, with 9 in. stroke and 30 strokes per minute. How much water is raised in one hour?

Then $3^2 \times \cdot 034 \times \cdot 75 \times 30 \times 60 = 413{\cdot}1$ gallons.

Worked as follows:

$3^2 = 9$ in.
× ·034 = Contents in gals. of 1 ft. of 1 in. pipe.
·306 = Contents in gals. of 1 ft. of 3 in. pipe.
× ·75 = 9 in. in decimal parts of 1 ft.
1530
2142
·22950 = Contents in gals. of 9 in. of 3 in. pipe.
× 30 Number of strokes per minute.
6·88500 = Gals. per minute.
× 60 Number of minutes in one hour.
413·10000 = Gals. per hour, the answer.

Another example with a 4 in. pump, 12 in. stroke and 20 strokes per minute.

Then $4^2 \times ·034 \times 1 \times 20 \times 60 = 652·8$ gallons per hour.

The rule can be varied to find other factors besides the quantity raised. As an example: Find the diameter of a pump to deliver 1,500 gallons per hour with a 12 in. stroke worked at 20 strokes per minute.

The rule arranged as a formula is

$$D = \sqrt{\overline{C \times S \times M \times L}}$$

Where G = Gallons raised.
D = Diameter of the pump in inches.
C = Contents in gallons of 1 ft. of 1 in. pipe = ·034.
S = Strokes per minute.
M = Minutes per hour.
L = Length of stroke in feet.

Then

$$D = \sqrt{\frac{1500}{\cdot 034 \times 20 \times 60 \times 1}} = 6{\cdot}063 \text{ in.}$$

or say 6 in. the diameter required.

Or assuming that we want to find the length of stroke, other particulars being given.

Example :—A 4 in. pump, 25 strokes per minute and 700 gallons raised per hour.

The simplest method is to first find what the pump would discharge with a 12 in. stroke.

Then $4^2 \times \cdot 034 \times 25 \times 60 \times 1 = 816$ gallons discharged with a 12 in. stroke.

And as 816 gals. : 12 in. : : 700 gals. : 10·294 in., which is the length of stroke for 700 gals.

In these calculations the length of stroke was taken as representing the length of a column of water of the same sectional area as the pump barrel, discharged at each completed motion of the handle. When the latter is raised, part of the bucket rod and bucket, which was above the water line, is immersed and displaces some of the contents of the barrel and causes them to flow out of the nozzle. On pulling down the handle, the bucket rod is raised out of the water, and the quantity flowing out of the nozzle is not the full contents of the barrel but is minus the space which was occupied by the rod. But the completed up and down stroke raises the quantity which was found by the calculations.

There is some little difference between the theoretical and the actual work done by a pump. The former has already been dealt with. To get the full effect the pump must (*a*) be in thorough

order and condition, (*b*) worked at a certain speed, (*c*) the bucket should work concentrically with the barrel, and (*d*) be fixed with due regard to the principles that have been laid down. Failing these conditions the results are below those arrived at in our calculations.

Dealing with (*a*) If the pump has holes in the suction pipe, air will be drawn in and less water will be delivered. If the bucket leather is much worn, or the inside of the barrel bruised, or roughened by corrosion, or if the clack leathers do not fit tight, less water would be delivered and an allowance for 'slip' must be made in all calculations. (*b*) All pumps work best at certain speeds. If worked too fast or too slow the full effect is not attained, although slow speeds do less injury than the fast to the working parts. Pumps with long strokes, worked at moderate speeds, are more effective than those which are worked at a quick rate with short strokes. (*c*) A reference to Fig. 1 will show that with ordinary jack pumps the bucket does not work concentrically with the barrel, but rocks, so to speak, to and fro as it moves up and down. Two sides of the bucket and corresponding inside portions of the barrel are subjected to excessive wear, and in this case, too, an allowance must be made for 'slip.' (*d*) When pumps are fixed too far from the well water, none at all is raised; but if just within the prescribed limits a lesser quantity is delivered than would be the case if the height were less. When the handle is not properly mounted, or if the bolt or its bearings, or the hole in the handle, is much worn, the length of the stroke is shortened, and although the exertions of the man are nearly the same, the

results are below what they would be if all the arrangements were perfect.

The allowance for 'slip' has to be varied, according to circumstances, from ·025 per cent. for new pumps, as the sucker clack is in the act of closing, to 30 or 40 per cent. for old pumps. Example: with a 2 in. pump, 8 in. stroke, 30 strokes a minute, slip, 10 per cent. How much water raised in half an hour?

$$G = 2^2 \times \cdot 034 \times \cdot 66 \times 30 \times 30 = 80 \cdot 784$$

and $80 \cdot 784 - 10$ per cent. $= 72 \cdot 706$ gals. actually delivered.

To vary the last example, assume a cistern holds 500 gals., and it takes a man just one hour to fill it with a 4 in. pump having a 12 in. stroke and worked at the rate of 25 strokes per minute. What is the proportion of slip?

If the pump was in good order $4^2 \times 1 \times \cdot 034 \times 25 \times 60 = 816$ gals., the actual quantity which would have been raised. But as only 500 gals. are pumped into the cistern we have $816 - 500 = 316$ gals. to allow for as having escaped past the bucket and sucker when pumping.

Then: As 816 : 100 :: 316 : 38·725, the percentage of slip owing to the defective pump.

CHAPTER V

The Strength of Lead Suction Pipes and Barrels

WITH regard to the strength of materials for pumps the lead suction pipes should not be less than those in the following table for good work.

Size of bore of pipe	Weight in lbs per yard lineal	For pump whose diameter is
1 in.	12	2 in.
1½ in.	20	3 in.
2 in.	27	4 in.
3 in.	35	6 in.

The weights can be slightly reduced for cheap work. Those in the table average from about 1·5th in. thick for 1 in. pipe to ¼ in. for 3 in pipe. Suction pipes do not have to resist a bursting pressure, that is, an internal force pressing outwards, but an external or outside force tending to crush the pipe. This outside pressure is exerted by the atmosphere.

For the barrels the lead should be from ⅜ in. to ½ in. thick, the lesser thickness being for barrels made of drawn lead pipe, or plate lead turned up and having ladle-burnt seams, and the heavier substance when the barrels are cast.

When suction pipes are laid in ground which has lime or old mortar in it they will become corroded and have holes eaten through them. Even when the upper courses of the brick steining of a well have been embedded in mortar and the suction pipe has been passed through, or built in, it has been injured by the above action. Hence the advisability of preventing any contact with lime or cement by surrounding the lead pipe with clay, dry bricks or other suitable material.

STRENGTH OF PUMP HANDLES

With regard to the strength of the handle, which is usually made of iron, the greatest strain is near the plank pin, or fulcrum, and this part requires to be stronger than at the extremities at which the power is applied or the weight is suspended.

The rule for finding the strength of a pump handle is the same as for finding the strength of a beam which is fixed at one end and loaded at the other, and is :—

Multiply the transverse strength of iron in lbs. by the breadth and by the depth squared in inches and divide by the length also in inches.

From the Ordnance experiments[1] the mean transverse breaking weight necessary to break a bar 1 in. square, projecting horizontally 1 in. beyond the support, the weight being at the free end, is 7,102 lbs. If we divide this by 4 we have 1,775 lbs. as being a load it would carry in safety.

If we assume that a pump handle is 42 in.

[1] Molesworth.

long from the centre of the plank pin to the part gripped by the hands, and is 1 in. square in section at its strongest point, we then have

$$\frac{1775 \times 1 \times 1^2}{42} = 42{\cdot}26 \text{ lbs. as the weight}$$

it would safely support at the end of the handle if it were horizontal and the short arm rigidly fixed.

As the man pulls down with a power of only about 20 lbs. the handle appears to be twice as strong as is necessary and could be reduced to one-half its sectional area. But it must be remembered that the 20 lbs. was assumed as an average for continuous work when pumping. At the commencement of the stroke the applied power is above this, although it lasts for only a fraction of a second. And, again, if a reduction is made it should be in the width and not in the depth of the section of the iron. If this were done we should then have the handle at its strongest part ½ in. wide by 1 in. deep. The width of ½ in. would be so small that any side motion of the handle would probably bend it, and for this reason the width of 1 in. should be retained for stiffening purposes. Another reason why the width should not be reduced is because so small a surface of the handle hole would rest on the plank pin that they would mutually wear each other away very quickly. A much worn plank pin was shown by Fig. 3. For large pumps which require two men to work them, or for lift pumps for raising water to great heights, or to tanks at the tops of high houses, the strength of the handles

should be increased beyond the example dealt with. Such increase of size should be in the depth of the section in preference to the width.

The remainder of the handle can be gradually reduced in thickness, lesser strength being required as the power, or man's hands, is approached. But this reduction must not be made to the extent of the actual strength required, or the lower extremity of the handle would be so thin as to be uncomfortable for gripping. In practice a bulb is generally made at the end, not only for this reason, but, as before explained, to aid the worker by its weight when pulling down.

THICKNESS OF BUCKET ROD

The thickness of the bucket rod may now be considered. The average breaking weight per circular inch of wrought iron is 15·7 tons, and for circular $\frac{1}{8}$ in. 550 lbs.[1] As these are the breaking weights an allowance should be made for safe working, and this allowance is usually considered as being one fourth the breaking weight. And $550 \div 4 = 137{\cdot}2$ lbs. as being the weight safely carried by an iron rod $\frac{1}{8}$ in. in diameter. Where the water has a corrosive action on lead and dissolves some of that metal, iron immersed in such water rusts with very great violence. By rusting of the iron the substance of the bucket rod is reduced considerably and much weakened. If an extra allowance is made for this, and the breaking strength of the rod divided by 8 instead of by 4, we have 68·75 lbs. as being the weight which can

[1] *Clarke's 'Tables for Plumbers'* (Batsford).

be safely lifted by a rod $\frac{1}{8}$ in. thick after it has been reduced by corrosion to the assumed extent.

The weights lifted when pumping have been before worked out, but another example may be taken to save reference.

Say a 4 in. pump is fixed at a height of 25 ft. from the top of the bucket to the surface of the water in the well.

Then $4^2 \times \cdot 34 \times 25 = 136$ lbs. of water to be lifted. To this should be added the extra friction of the water at the commencement of the stroke, and also the friction of the bucket in the barrel. After making such allowances it will be found that a bucket rod $\frac{1}{8}$ in. thick, is only half the strength required for lifting the load. Although theoretically strong enough, a rod twice as strong, or ·176 in. thick, would not do at all in practice when pumping. The motion is a pull and thrust one, and the worker would sometimes be 'jerky' in his movements. With a jack pump the movement of the rod is not always in a vertical line, but is sometimes in a slanting direction, as the top end rocks to and fro in the front and back sides of the barrel. To have the necessary strength and stiffness, bucket rods should be not less than $\frac{3}{8}$ in. to $\frac{5}{8}$ in. in diameter, according to the size of the pump

CHAPTER VI

Long Barrel Pumps

Hitherto ordinary lead jack pumps fixed above the level of the ground have been dealt with. But there are many cases where the well water is so low down that pumps so fixed would be useless. In many country places the water, although low, is within a reasonable distance, and a long barrel jack pump made especially for the purpose is used, and the cost of a 'lift pump' and its fittings avoided.

Assume a case where the water is 35 ft. below the surface of the ground, and the pump is required to raise water to fill a cart, the top of which is 7 ft. above ground level, the men to stand on a raised platform to work the handle.

In such a case the bucket must work within the limits that have been already laid down.

Then $35+7=42$ ft., the height the water has to be lifted. If the limited distance between the well water and the bucket is taken as being 25 ft., then $42-25=17$ ft. And the pump sucker must be that distance below the top of the barrel. A pump for this purpose should have a very long barrel, the total length of which should be $17+$ extra length at top to form a head, or say a length of 18 ft. in all. Such a pump is shown fixed in a well by Fig. 16. The barrel fixings must be

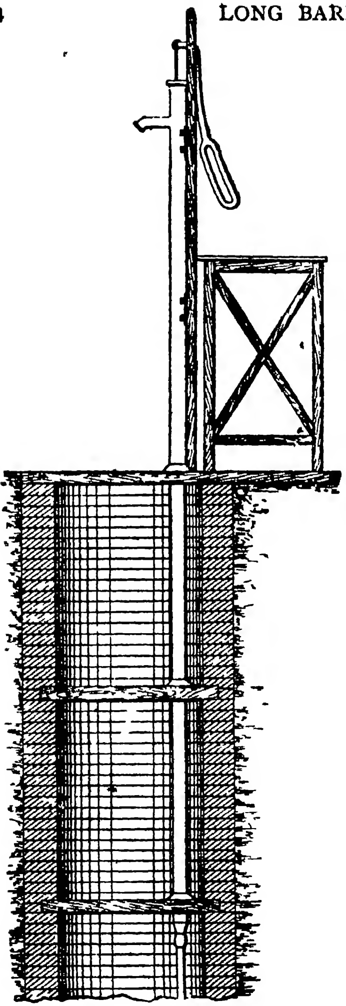

FIG. 16.

very strong, and are best made with wiped flange joints supported on oak stages with the ends built into the brick steining, as shown in the figure.

As it would be very difficult to fix the sucker or take it out for repairs if it was as shown by Figs. 1 and 5, a different kind of sucker valve is necessary. Spherical, or ball, valves, as shown by Fig. 17, can be used. The ball and seating are made of gun-metal and soldered between the barrel and tail piece, as shown by the fragmentary section. This valve, to be taken out for any purpose, requires a 'door,' as shown at A, and which consists of a good size very strong brass or gun-metal cap and

screw soldered in the side of the barrel. The disadvantages of this valve are, grit prevents the valve 'seating' properly; the ball can be changed, but not the seating, without unsoldering the joint to the tail piece; and, if the pump is being worked very quickly, the ball rises too high, and a considerable quantity of water 'slips' before the valve reseats itself.

Another kind of valve is shown in section by Fig. 18. This

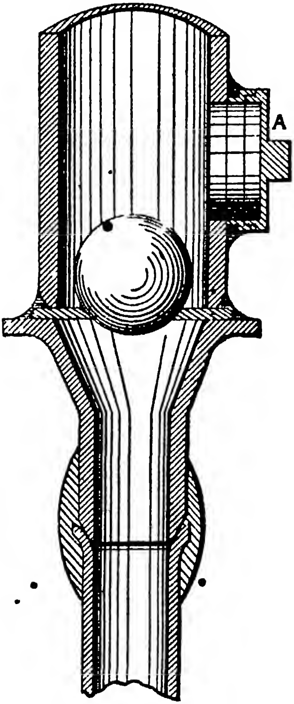

FIG. 17.

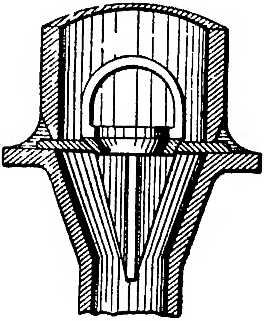

FIG. 18.

consists of a 'ground-in' valve with a 'feather' guide on the under side and a 'bow' top for lifting out with a hook on a rod through the top end of the pump barrel.

A valve, either 'ground-in' or with a leather washer, and with a very long spindle, as shown by Fig. 19, is sometimes used. This valve has a guide for the spindle to work in, and can be lifted out similar to the last one. A disadvantage of this valve is that, in fixing it, two joints are necessary. The body has first to be soldered

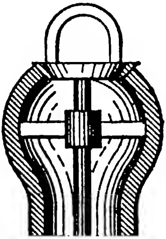

FIG. 19.

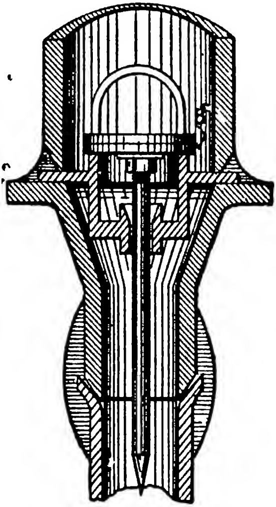

FIG. 20.

to the top end of the suction pipe, and a second joint made between the latter pipe and the barrel. Unless great care is taken the first joint is liable to be melted when making the last one.

There are many other methods adopted, but the simplest is shown by Fig. 20. With this valve the seating is raised so that grit or very small

pebbles fall on one side and do not make the valve leak. The valve can be lifted out from the top of the barrel to have the leather B renewed. The brass seating has a flat top, instead of an edge which would cut into the leather. The spindle is very long to prevent the valve jumping out of its position when pumping. The end of the spindle is pointed, and the hole through the guide bar is 'mouthed' for the more readily dropping of the valve into its position. The water-way is as large as possible so that the valve does not rise too high, when pumping, with consequent less 'slip' in recovering its seating.

Pumps with very long barrels do not have such long strokes as those with short barrels, as the rocking motion of the top end of the rod, as before referred to, knocks against the front and back sides of the top to a greater extent. To prevent this knocking the arc described by the end of the short arm of the handle has to be reduced, and by so doing the length of the stroke is shortened and less water is delivered.

PUMPS WITH TWO NOZZLES

Another kind of jack pump is fitted with two nozzles; the lower one for filling pails, &c., and the higher one for filling carts, or, as experienced by the writer, filling the copper at a small country brewery. Such a pump is shown by Fig. 21. The lower nozzle has a cap screwed on the end when the water is to be raised to the level of the upper nozzle. The figure also shows a compound pump handle, which can be used when the man is standing on the ground instead of on a raised platform.

By this arrangement there is no gain of power. As an example, assume that the short and long arms of the top lever are 6 in. and 9 in. respectively, that the pump has a 4 in. barrel and has to raise water 25 ft. above the well water measured to the under side of the nozzle. This gives 136 lbs. net weight to be lifted.

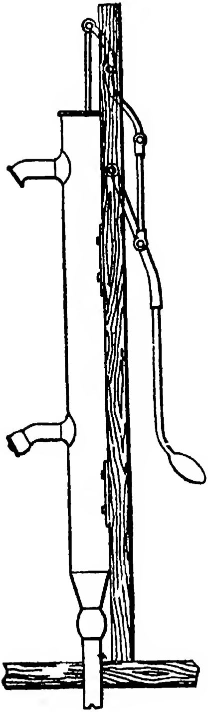

FIG 21.

$$\text{Then } \frac{6\text{ in.} \times 136\text{ lbs.}}{9\text{ in.}} = 91\text{ lbs}$$

of power to be applied to the long arm of the upper lever. This would be more power than an ordinary man could exert. In addition, the end of the lever is beyond his reach when standing on the ground. By the aid of the lower lever, or handle, the short arm of which is 9 in. and the long arm 36 in., we have

$$\frac{91\text{ lbs} \times 9\text{ in.}}{36\text{ in.}} = 23\text{ lbs. nearly}$$

as the power to be applied to the handle, and this is the same as if the lower lever had been connected directly on to the pump bucket. This working tends to show that with compound pump handles there is no gain of power, and they are only suitable for use under the conditions that have been described.

If the link connecting the rod of the upper lever to the lower lever was moved one or more inches nearer to the plank pin of the latter more power would be exerted, but the length of the bucket stroke would be reduced, and this would result in less water being delivered at each completed stroke.

BOW-HANDLE PUMPS

Where two men are necessary for working a pump it is an advantage to make the handle double, that is, have a large bow, as shown by Fig. 16, so that each man can grip independently of the other, and individual energy can be exercised to the utmost extent. When 6 in. or larger size pumps are used they are sometimes fitted with two handles mounted on the same axle, from which an arm projects for attaching to the bucket rod. Pumps with two handles and two nozzles are sometimes fixed in the country for supplying the cottages on each side of a party fence.

IRON PUMPS

In addition to lead, jack pumps are made of other materials, such as cast iron, brass, gun-metal, and galvanised sheet iron. The latter kind is generally mounted on an iron tripod, as shown by Fig. 22, and is used by contractors and builders for emptying foundation trenches and sumps. Instead of an iron tube suction, a flexible hose is sometimes connected by means of a brass union, a rose being attached to the lower end of the suction where necessary for preventing anything passing up with the

water to clog the sucker and bucket valves. A great many of these pumps, which are portable and are fitted with flexible suctions, are used in country places for emptying cesspools or filling carts with water from streams, ponds, and ditches, &c., for farm and other purposes. Water carts sometimes have similar pumps fixed to the sides with screw

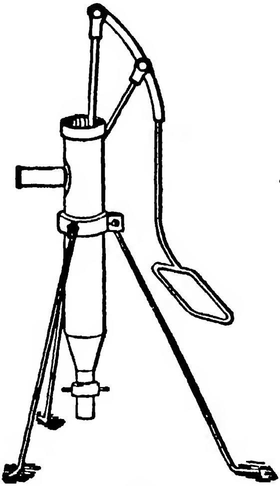

FIG. 22.

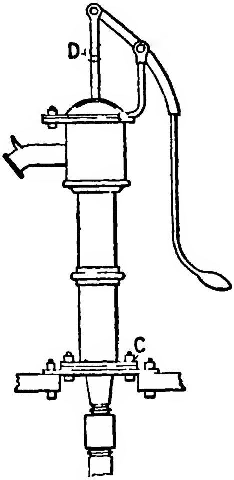

FIG. 23.

bolts. Ordinary contractor's pumps have galvanised sheet iron suctions, which are made in 6 ft. lengths, and have what may be termed coned joints. The upper end of each pipe has a trumpet mouth, into which the length above is tightly socketed and the joint made with clay.

Cast iron pumps are now much used. Some kinds are bolted to a base and do not require any up-

right planks or similar supports. Such pumps have flanged connections between the barrels and the tail pieces as shown at C, Fig. 23. The bottom valve or 'sucker' consists of a piece of leather cut as shown by Fig. 24, and is bolted between the bottom flanges. With some pumps the clack, shown in the centre of the last figure, has a stud, on the top of the side next the hinge, which stands up as shown by Fig. 25 This stud prevents the clack opening too wide. and is also useful for emptying the barrel in frosty weather. To empty the barrel the handle is raised to the utmost extent, when the bucket rests on the stud, opens the valve, and allows the water to run away down the suction pipe.

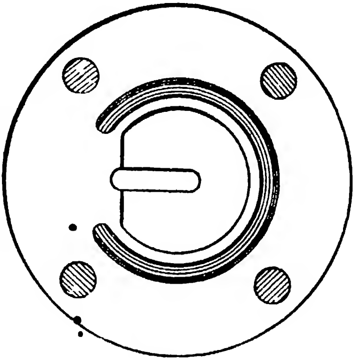

FIG. 24.

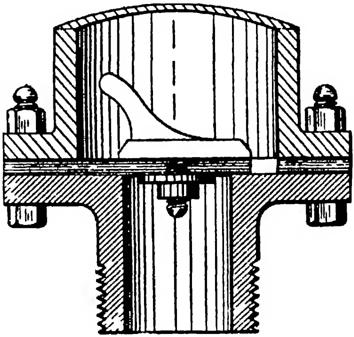

FIG. 25.

Some of these pumps have brass union connections, as Fig. 26, instead of the tail piece being screwed for iron as

shown in Fig. 25. And, instead of the flange for fixing to a stone or oak base, have lugs cast on the barrel for fixing to a plank or a wall. Others again have cast iron brackets for bolting to walls as fixings.

Nearly all iron jack pumps have iron caps or covers on the tops of the barrels similar to those shown in Figs. 23 and 26. In Fig. 23 the hole for the bucket rod to work in is slotted to allow for the rocking motion that has been before mentioned. These pumps have many other forms, besides the one shown, and amongst these may be mentioned those having the handles mounted in slotted projections on the sides of the heads With these the bucket rods work beneath, instead of through, the cappings or covers.

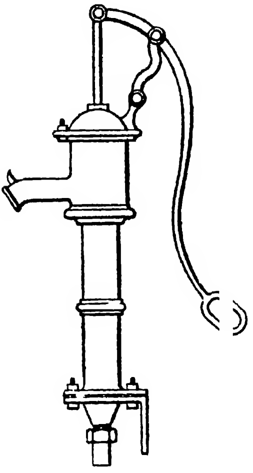

FIG. 26.

With pumps which have the rods working through the top, and to avoid the caps being slotted, the handles are mounted on 'swivels' or 'vibrating links,' as Fig. 26. This figure also shows a base bracket for bolting to a wall The bracket should be at the side and not under the handle as drawn. The vibrating link is for the purpose of allowing the bucket rod to work vertically through the cover. The rod is stiffer than for ordinary pumps, to resist being bent against the sides of the hole in the cap which acts as a guide.

Another make of these pumps has the vibrating link attached to the short arm of the handle, with a kind of rule joint to the bucket rod, as shown by dotted lines at D, Fig. 23. In this case the handle is mounted on a fixed standard, attached to the pump, higher than that shown in the figure, to allow the handle to be worked without the joint knocking against the cover.

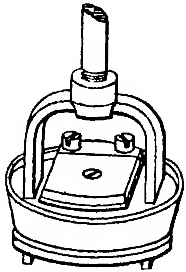

FIG. 27.

With the cheaper kinds of iron pumps wooden 'buckets,' similar to that shown by Fig. 2, are used, but these are not nearly so good as those made of brass or gun-metal, as shown by Fig. 27.

HOT LIQUOR PUMPS

Pumps of all kinds used for hot liquors should have 'quilted' canvas cups and flanges instead of those made of leather, the latter material being injured by the action of hot water. The cups and flanges are made of specially prepared canvas, which is cut to shape, and then three or four thicknesses are sewn together by 'overcasting' all the edges to prevent them fraying out. The centre parts are quilted by sewing through, the stitching being evenly done and a short distance apart, to what may be termed a 'herring bone' pattern. These cups and flanges can be made by plumbers, but are much better when bought of dealers in plumbers' materials who have them made in a proper manner. Fig. 28 is a sketch of

a quilted cup showing the stitching. Buckets with quilted cups for hot liquor generally have ground-in brass valves. Fig. 29 is a quilted bottom or sucker flange.

A great deal more could be written on the various kinds of jack pumps, but most of the

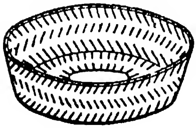

FIG. 28

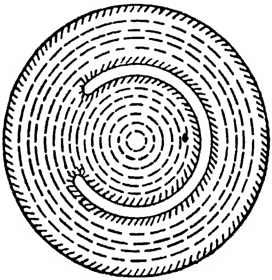

FIG. 29.

principal points have now been alluded to, and others will be under the next heading of lift pumps. These will now be dealt with in the same manner as we did with jack pumps, commencing with their various parts and construction.

CHAPTER VII

Lift Pumps

As a preliminary it may be stated that a lift pump is used for raising water to a position higher than itself.

If a lead jack pump had the top of the barrel and also the hole through which the bucket rod works made water-tight, the nozzle turned upwards and a pipe soldered to it for conveying the water to any desired position, it would then be what is commonly called a 'lift pump.' Jack pumps are frequently called lift pumps, and the latter 'lift and force pumps.' In these lectures it is proposed to speak of each kind separately, so as to avoid confusion, and allude to 'force pumps' as those having solid plungers or pistons.

A simple, or what may be called home-made example of a lift pump, as sometimes found in country places, is shown by Fig. 30.

The barrel is lead, and the same as for a jack pump, excepting that, instead of an open head, a brass stuffing box and flange is soldered on at E. The delivery pipe F is soldered to the side of the barrel, as close to the top as possible. The bucket is made of elm, as for an ordinary jack pump, and the barrel has to be a little longer than usual to

allow for the length of the bucket. Brass buckets, as Fig. 27, are also used, and for these the barrel need not be quite so long. The sucker is made of elm, but brass sucker boxes can be bought for either cementing or soldering to the tail of the pump.

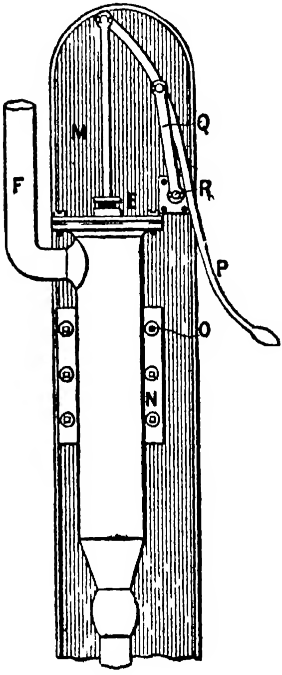

FIG. 30.

Fig. 31 is an enlarged section of the flange and stuffing box. G is the bucket rod made of copper, H the screw for compressing the stuffing or packing, I, as close to the rod as possible for preventing the water escaping, J J are the pump screws (the best are made of copper), K is a leather washer, and L a brass flange soldered to the lead barrel. The latter is fixed to a plank M, Fig. 30, by means of strong lead face-soldered tacks, N, and square headed, or coach, screws with flanged heads as at O. The pump handle P is mounted on an oscillating link Q and axis R, which is screwed to the plank.

On referring to the illustration it will be noticed that no valve is shown on the delivery pipe. Neither is one necessary, excepting in cases where the lift is very high. With low lifts, say

10 ft or 20 ft., it may be considered an advantage not to have this valve, as should it be required to recharge the barrel prior to working it, this can be done by pouring water down the delivery pipe. With a valve fixed, and if the valve is sound, the water cannot run into the barrel.

Lift and force pumps have the length of their suction pipes limited to the same extent as jack pumps, and should never be fixed more than 25 ft. above the well water. And it necessarily follows that in a deep well the pump has to be fixed inside the well and below the ground surface. In such a case it would be supported on a plank; fixed either to the well steining or to a platform. The pump would be worked by a handle or a winch above the surface of the ground, but immediately over the well, and have a long bucket rod from the handle to the pump.

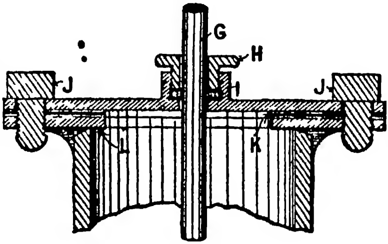

FIG. 31.

Under these conditions a valve and air vessel should be fixed on the delivery pipe, as close to the pump as possible.

Hand-made leaden lift pumps are not now so much used as those made of brass or gun-metal. An illustration of the latter is shown by Fig. 32. The barrel S is brass or gun-metal, as are also the tail piece T and stuffing box U. The rod V is copper and continued through the iron guide W, which has a brass bush for the rod to work through.

The sling X is made of wrought iron, and connected to the handle Y and the bucket rod V respectively by the bolts A. The use of the sling and guide is to keep the rod straight and prevent it vibrating. But for these the rod would be either bent or worn away by friction against the stuffing box. To prevent bending the bucket rod and to avoid the use of the guide and sling the handle could be mounted on a vibrating standard, as shown by Fig. 30 at Q, but this is not nearly so good as the guide and sling. With the pump illustrated by Fig. 32, the axis, or bolt, is in one piece with the handle and works in the carriage B, which has brass bushed holes for the axis to work in. When water has to be lifted to a great height a valve is fixed at C, and an air vessel (usually made of copper) at D. For a very deep well the pump would have a base flange, and be fixed on a bearer in the well and nearer to the water. The air vessel should be attached to the pump delivery arm as shown, but the working handle and plank should be fixed at or above ground level with a long rod to the pump, as before stated.

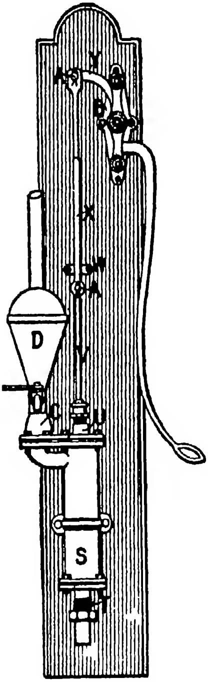

FIG. 32.

CHAPTER VIII

The Use of an Air Vessel on the Delivery Pipe

Before describing other lift pumps and their working parts, it may here be considered convenient to explain the use of an air vessel on the delivery arm of a pump. A sketch of an air vessel was shown by Fig. 14 to illustrate its use on a suction pipe. Under those conditions the air is rarefied or expanded, but when fixed in the delivery pipe the air is compressed or made to occupy a lesser space. A further sketch is here shown, Fig. 33, to aid the description. D is a section of the vessel in which the delivery pipe E is continued through the top and nearly to the bottom. When the pump is first fixed the vessel is filled with air, but after pumping for some time the water rises in the vessel and pushes the air into the upper portion where it cannot escape. Assuming that the pump has been worked long enough to fill the delivery pipe, and the water stands in the vessel to the height shown in the figure when the pump and the water are at rest, the next time the handle is pulled down more water is forced in and the air further compressed, say to the dotted line, F.

The labour of compressing the air is not nearly so much as would be required to suddenly over-

come the inertia of the water in the delivery pipe and put it in motion. But as the air is in a state of being compressed to a greater degree than is exercised by the dead weight of the water in the pipe above, it naturally begins to return to its first condition of density at the end of the stroke, and in expanding pushes some of the water out of the vessel and up the delivery pipe. During the time this is occurring the handle is being raised for the next stroke. On pulling the handle down, the water being already in motion, so much resistance is not offered and consequently the pump is worked more easily.

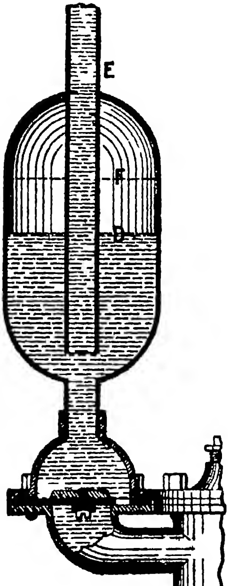

FIG. 33.

A few calculations may aid to make clear the economy in labour by using an air vessel. Assume that a delivery pipe is 100 ft. long, 50 ft. being vertical and 50 ft. horizontal. The horizontal portion of the pipe has no effect on the pressure in the air vessel, but has a considerable influence on the working of the pump, not only on account of the friction of the water when flowing through the pipe, but also in overcoming the inertia of the water and putting it into motion when starting to pump.

The 50 ft. of vertical column of water exerts a pressure of 21·67 lbs. on each square inch inside

the vessel. This is found by a previous rule by which 50 ft. × ·4334 = 21·67 lbs. The pressure exerted by the atmosphere at sea level is 14·7 lbs. per square inch, and the water in the air vessel exerts a pressure of nearly one and a half atmospheres above the normal. A volume of air confined in any vessel simply fills it under ordinary conditions, but it will hold twice the quantity when the bulk is reduced by an additional pressure of one atmosphere.

To more fully explain the extent of the air compression we will refer to what is known as 'Boyle's Law,' and which is as follows :—*The temperature remaining the same, a volume of a given quantity of gas is inversely as the pressure which it bears.*

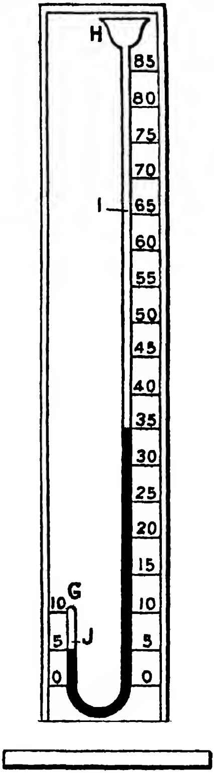

FIG. 34.

For demonstrating this principle a glass tube on a stand, as shown by Fig. 34, and known as a Boyle's tube, is requisite.[1] The end, G, is sealed or made perfectly airtight. A little mercury is poured in the open end, H, until the tube is filled to 0, or zero, on the two scales, which are in this case divided into inches, on each side of the bend.

[1] On the Continent this is known as Marriotte's tube.

Some little trouble is experienced in getting the mercury to stand at the same height in both legs owing to the air being slightly compressed in the short leg. But by tipping the tube two or three times success can be obtained. When properly charged the air pressure on the mercury is the same in both tubes.

It has before been demonstrated that the ordinary atmospheric pressure is equal to a column of mercury 30 inches high. If the long leg of the tube is filled with mercury to a height of 30 inches, measured from the surfaces of the two columns, as shown in the figure, the air in the short leg will be found to occupy half the space it did at first, thus showing that with double the pressure the air is reduced to a space equal to half its original bulk. If more mercury is poured into the long tube until it stands at a further height of 30 inches, as at I in the figure, this would be equal to another atmosphere of pressure, and the pent-up air in the short leg would be further reduced and occupy one third its original space, as the mercury would rise to J in the short leg. Another 30 inches of mercury would again reduce the confined air, and it would be contained in one fourth the space it occupied when starting the experiments.

The following table is calculated on this basis and the assumption that the ordinary pressure of the atmosphere is zero.

In the pump problem, with 50 ft. head of water in the delivery pipe it was found that the pressure of about $1\frac{1}{2}$ atmospheres was exercised in compressing the air in the vessel. This pressure would reduce the air to about 5-12ths of its original bulk. The approximate working of this

No. of atmospheres	Air compressed in volume in air vessel	Space occupied by water in air vessel	Height of column of water in delivery pipe	
			ft.	in.
1	0	0	0	0
2	$\frac{1}{2}$	$\frac{1}{2}$	33	$10\frac{1}{2}$
3	$\frac{1}{3}$	$\frac{2}{3}$	67	9
4	$\frac{1}{4}$	$\frac{3}{4}$	101	$7\frac{1}{2}$
5	$\frac{1}{5}$	$\frac{4}{5}$	135	6
6	$\frac{1}{6}$	$\frac{5}{6}$	169	$4\frac{1}{2}$

we get from the second column in the table, where the pressure of one additional atmosphere reduces the air to one half, and two atmospheres to one third. Then $\frac{1}{2} + \frac{1}{3} \div 2 = \frac{2.5}{6}$ and this reduced to a simple fraction = 5-12ths for $1\frac{1}{2}$ atmospheres.

Fig. 35 is a diagram showing more correctly the amount of compression that takes place from unity to ten atmospheres. To avoid having too many lines to interfere with the clearness of the drawing, the bottom side is divided into atmospheres and subdivided into spaces, each representing 5 in. of mercury. The side of the figure is divided to represent the amount of air compression which takes place from two to ten atmospheres, and the curved line the height of the surface of the water under the various pressures.

By this illustration intermediate readings can be taken. As an example, assume an air vessel has parallel sides and flat ends, and that the top and bottom lines in the figure represent the ends.

At what height would the water stand under a pressure of 15 in. of mercury or half an atmosphere above zero? On looking up the third line from 1, it is found to cut the curve at K. Or where would the surface of the water be under 70 in. of mercury? This is equal to two atmospheres + two of the division lines, and it is found to be at L.

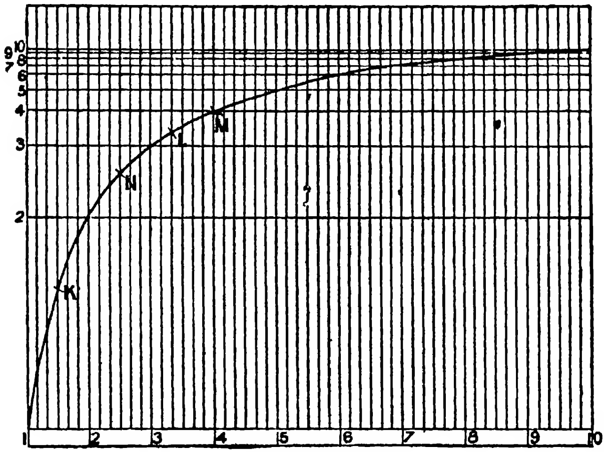

FIG. 35.

At the commencement of the stroke sufficient effort has to be exerted to raise the weight of the 50 ft column of water above the pump + an allowance for friction in the total length of 100 ft. of delivery pipe. The pressure on the pump bucket due to head (assuming a 4 in. pump) $= 4^2 \times$ $\cdot 34 \times 50 = 272$ lbs. In the absence of exact data to work from assume that the friction in

starting movement in the water is equal to 30 per cent. of the load being lifted. And 272 + 30 per cent. = 353·6 lbs. dead weight at the commencement of the stroke when no air vessel is used.

With an air vessel the load is considerably less when starting to pump, as the water is forced into a chamber against the resistance of the contained air, which, although compressed, is so elastic that it can be made to occupy less space. The compressed air offers a resistance equal to the weight of the column of water, or 272 lbs. only. If, at the commencement, the handle was pulled down very quickly, so that the contents of the pump barrel were forced into the air vessel before the water in the delivery pipe had time to be put in motion, the pressure would be sufficient to reduce the air space to the same extent as about an additional 1½ atmospheres. In such a case the water line would be at M, Fig. 35, N being the height before starting. From this we conclude that the friction in the delivery pipe is very much reduced at starting, and less labour has to be exerted under the given conditions.

And then, again, assume that a pump is being worked at the rate of 30 strokes per minute, one second being occupied in the up and one second in the down stroke. A quantity of water equal to the contents of the barrel is emptied in every alternate second and, without an air vessel, the motion of the water is arrested and restarted during the same times. But with an air vessel the motion is continuous during both up and down strokes, and, speaking approximately, the friction of the moving water is reduced by about three quarters.

An air vessel has another advantage in that a pump so fitted will last considerably longer, and the bucket will not work loose or break away from the rod so frequently as without an air vessel.

The noise made by the rush of water through the delivery pipes, and also the thud heard at each stroke of the pump, are both minimised by the use of a confined body of air, which acts as a cushion or spring for the water to press against.

The above reasoning applies to air vessels in suction as well as in delivery pipes.

SUBSTITUTE FOR AN AIR VESSEL

There is an impression in some parts of the country that a hopper head and nozzle fixed on the upper end of a pump delivery pipe, as shown at V, Fig. 36, has the same effect as an air vessel fixed to the pump. When the pump is being worked the water is forced at each stroke into the head faster than the nozzle will take it away, and the water continues to flow during the reverse action of the pump, thus giving the impression that the water is in continuous motion in the delivery pipe. This is not so, as the water in the rising pipe alternately stops

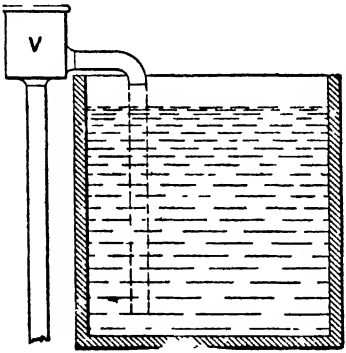

FIG. 36.

and starts in unison with the action of the pump. The only advantage of the head is the reduction of the plunging noise made by the water falling into that in the cistern. A common complaint in country mansions, where cisterns are fixed in roofs over bedrooms, is made of the thud made by the water as it is forced into the cisterns. By fixing a head and continuing the nozzle to nearly the bottom of the cistern, as shown by dotted lines, the splashing noise is not heard. The head should be partially covered but have an air opening, otherwise, with a defective pump, the contents of the cistern would be siphoned back into the well.

For reasons that have been fully dealt with an air vessel should always be fixed to any pump by which water is raised to any considerable height. The hopper head on the delivery pipe, as shown in Fig. 36, is of little or no value.

CHAPTER IX

Size of Pump Governed by Available Power to Work it

The size of the handle and the power necessary to work a lift pump will now be considered Assume a pump is fixed 20 ft. above the surface of the well water, and has to raise water to a further height of 50 feet.

Then 20 ft. + 50 ft. = 70 ft., total height the water has to be raised. And $70 \times 4^2 \times {\cdot}34 = 380{\cdot}8$ lbs. to be lifted by the bucket. If the short arm of the handle is 6 in. long, and the man can pull down with his hands with a power of 20 lbs., we have $\frac{380{\cdot}8 \text{ lbs.} \times 6 \text{ in.}}{20} = 114{\cdot}24$ in., or a little over $9\frac{1}{2}$ ft., the length necessary for the handle. Such a length could not be worked, and if the handle was a double one, but half the length, so that two men could use it, it would then be over $4\frac{1}{2}$ ft. long. This goes to prove that under these conditions a 4 in. pump could not be used, and a smaller size should be fixed. It could be found by experiment what smaller size pump could be worked, but the readiest way will be to apply another rule and find the smallest actual size at once. Expressed as a formula the rule would be ;—

$$D = \sqrt{\left(\frac{L \times P}{W \times S}\right)}$$

Where D = the diameter of the pump in inches.
L = length of long arm of handle in inches.
S = length of short arm of handle in inches.
P = power of man in lbs.
W = weight on each circular inch on the bucket in lbs.

In our problem we will assume that

$$\begin{aligned} L &= 36 \text{ in.} \\ S &= 6 \text{ in.} \\ P &= 20 \text{ lbs.} \\ W &= 70 \times {\cdot}34 = 23{\cdot}8 \text{ lbs.} \end{aligned}$$

Then

$$D = \sqrt{\left(\frac{36 \times 20}{23{\cdot}8 \times 6}\right)} = 2{\cdot}24 \text{ in. nearly}$$

as the largest diameter of the pump that could be used under the given conditions.

Here another detail has to be taken into consideration. If a given quantity of water has to be raised, the smaller size pump has either to be worked more quickly or for a longer period of time. The speed of working should not be increased at the risk of breaking some part of the pump fittings, so the time must be extended.

To work out an example. If a given quantity of water is raised in one hour by means of a 4 in. pump, how long would it take a $2\frac{1}{4}$ in. pump to raise the same quantity, all other conditions being equal? The simplest solution is to compare the sizes of the barrel. As stated in an earlier lecture,

circles are to each other as the squares of their diameters. Then $4^2 \div 2{\cdot}25^2 = 3{\cdot}16$, and $3{\cdot}16 = 3$ hours 9·6 minutes to raise the same quantity of water as the 4 in. did in one hour.

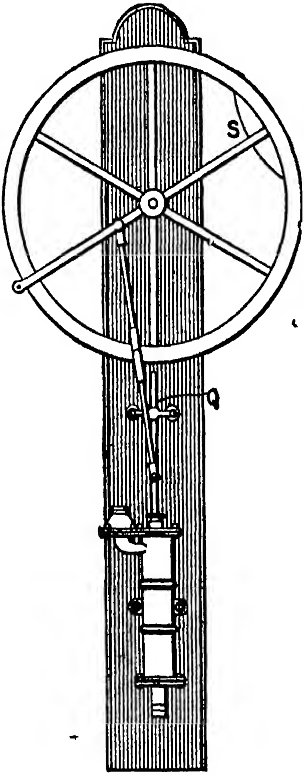

FIG. 37.

Practically there is no difference in the amount of work that can be got out of a lift pump, whether it is fixed above or below ground level. The same amount of energy has to be exerted with the barrel fixed in a well to raise water to the ground level, as with a barrel fixed above ground to fill a tank placed at the same height above the pump as the pump was below the ground. In other words, if the suction and delivery pipes are respectively of the same vertical length. When the pump is fixed below the ground the weight of the long bucket rod should be compensated by loading the end of the pump handle.

WINCH HANDLES TO PUMPS

Lift pumps on planks are sometimes worked by means of winch handles, as shown by Fig. 37, or the winch and plank are fixed above the ground, as Fig. 39, and the barrel in the well. Even when not actually necessary the barrel, when in cold or exposed positions, is sometimes best fixed below ground where it is beyond the reach of frost. A cock should be fixed near the pump for emptying the delivery or rising pipe when necessary to do so.

The power of a winch is calculated by rules which are almost similar to those of a lever. Let Fig. 38 represent a fly-wheel, winch and crank. The distance from the handle O to the centre of the crank shaft P being 20 in., and the length of the crank 5 in., measured from its centre to that of the shaft, the 20 in. will be the length of the long arm, and the 5 in. the length of the short arm of a lever. Then 20 in. ÷ 5 in. = 4, as representing the number of times the power of the long arm is increased over the resistance of the short arm. A man working at a winch can exert with his hands an average pressure of about 30 lbs. for continuous work, but for a short time this pressure could be exceeded.

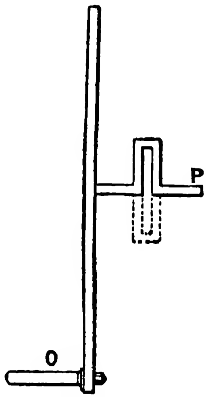

FIG. 38.

From this a formula can be deduced for finding

what size barrel and to what height the water can be raised by a man working the pump shown by Fig 37.

For finding the actual weight that can be lifted the rule is

$$W = \frac{P \times L}{S}$$

Where P = the man's power.

L = the distance between the handle and centre of crank shaft.

S = the distance between centres of crank and shaft

W = the weight that can be raised.

As an example:

Let P = 30 lbs, L = 20 in, S = 5 in.

$$\text{Then } W = \frac{30 \times 20}{5} = 120 \text{ lbs}$$

To apply this rule: To what height could a man raise water with a 3 in pump under the foregoing conditions?

Then $3^2 \times {\cdot}34 = 3{\cdot}06$ lbs weight for each foot in height the water is to be raised

And $120 \div 3{\cdot}06 = 39{\cdot}2$ ft. total height, measured from the surface of the water in the well to the top end of the delivery pipe, that the water could be raised. The work done and the power exerted would be equal to each other, as worked out in the problem, and the height to which the water could be raised would be less than that given.

As another example: What is the largest size pump, fitted as Fig. 37, that could be used for raising water to a height of 60 ft. above that in the well?

The formula then becomes

$$D=\sqrt{\frac{P\times L}{S\times H\times W}}$$

Where P = man's power in lbs.
L = distance of handle from centre of crank shaft in inches.
S = distance between centres of crank and shaft in inches.
H = height in feet the water is to be lifted.
W = weight of water on a circular inch in the barrel for each foot of head = ·34 lbs.
D = diameter of pump in inches.

Then

$$D=\sqrt{\left(\frac{30\times 20}{6\times 60\times \cdot 34}\right)}=\frac{5}{1\cdot 02}=4\cdot 9$$

and $\sqrt{4\cdot 9}=2\cdot 213$ in., the diameter sought. Here again an equilibrium is established, and the pump should be a little less, so that the power may exceed the load.

This working out leads to the conclusion that the pump mounted as shown by Fig. 37 is only satisfactory when of a small size, or is used only for raising water to a moderate height.

The flywheel has an advantage in that, when fairly heavy, it steadies the action of the pump. By its momentum it carries the motion of the pump beyond those parts where the man can exercise the least power, such as when the handle is horizontal with the axis.

When the pump is fixed in the well, and the plank and winch are above ground, the guide Q, Fig. 37, should be attached to the plank, so that the motion of the bucket rod is always vertical. If

the sling and guide were attached to the pump the rod would rattle very much in the well, and by its oscillating movements would be liable to bending between the guide and winch.

Another wheel action is shown by Fig. 39. When the pump is fixed below ground the wheel is mounted on a plank, and instead of a guide and sling to the pump rod, a rocking bar, R, is fixed.

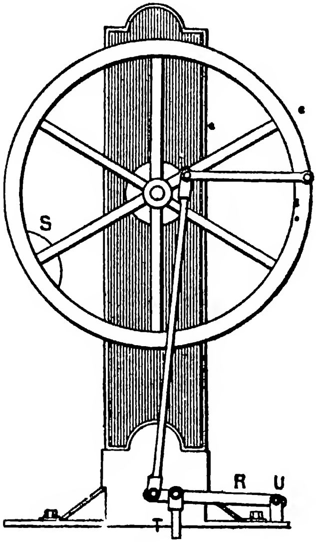

FIG. 39.

S S, Figs. 37 and 39, are counterpoises for balancing the weight of the rods and handles which are fixed on the opposite sides of the axles of the fly-wheels.

Not only is the rocking bar R, Fig. 39, useful for steadying the pump rod, but by its use there is a gain of power. To explain this, assume that the combined weights of the rod T and the bucket and water in the barrel are 360 lbs. If the bar R is 18 in. long, the centre, or rod, bolt 3 in. from the short and 15 in. from the long end, the long arm of the lever is five times the length of the short one and supports 1-6th of the load. The other 5-6ths hangs on to the winch crank. Then 1-6th of 360 = 60 and 5-6ths of 360 = 300 lbs. From this

it is found that when working a pump under the given conditions the load on the crank is lightened by 60 lbs.

A case came under the writer's notice a few years ago where the plumber, with a view to lengthening the stroke of the pump so as to throw more water, altered the connections to the rocking bar and attached the pump rod near the short end. The pump then worked so hard that one man could use it for only a short time. A calculation will show why this was so. Assume that the net weight to be lifted and other conditions were the same as in the last problem, but the couplings were changed. There are 360 lbs. hanging on the end above T, Fig. 39. By adopting the lever formula as previously described we get

$$\frac{360 \text{ lbs.} \times 3 \text{ in.}}{15 \text{ in.}} = 72 \text{ lbs.}$$

which equals the weight that should be hung on the end of the bar, represented by the resistance of the bolt U, to balance the weight hanging on the other end. In this case 72 lbs. × 15 in. are equal to 360 lbs. × 3 in. The net weight hanging from T being 360 lbs. and the counterbalance at U 72 lbs., the actual weight to be lifted by the man when pumping is (360 + 72 =) 432 lbs. By this will be seen the great increase of labour entailed by the alterations that were made by the plumber.

A winch pump and frame, with the front half of the frame removed, is shown by Fig. 40. With this appliance two men can work on opposite sides of the frame, and by doubling the manual power, water can be and is raised to a much greater

height than by a pump with a single handle at which one man only can exercise useful effort.

When the water exceeds 25 ft. below the ground level the winch should be on or above the surface of the ground, and the pump in the well.

On referring to the figure it will be noticed that the handles (one being shown by dotted lines) and crank are at right angles to each other, and these are the best relative positions. The greatest effort is required when the crank is horizontal, as the greatest weight is then being raised, and the bucket is travelling at the highest speed. When the crank is in the above position, and the handle either up or down, the worker either pulls or pushes, and his power may then be taken as equal to a pressure or force of about 40 lbs.

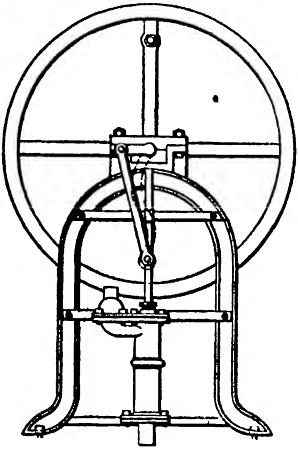

Fig. 40.

But when the handle is horizontal the man's power is equal to only about 20 lbs., and if the crank was parallel with the handle he would not be able to exercise his greatest power at the time the heaviest load was hanging on the crank. It was on this basis that the 30 lbs. average pressure by a man's hands was computed. The momentum of the fly-wheel helps to make his efforts more continuous and regular.

CHAPTER X

Double Barrel Deep Well Pump and Fittings

Fig. 41 shows a double barrel pump fixed in a well, W being the winch and frame, X the pump rods, Y the rising main, and Z the air vessel. The pumps are shown at A, the suction at B, and the strainer at C; D is the pump carriage or platform, and E the rod guides and stages.

In many cases the pumps have flanged bases, which are screwed on to oak stages, the ends of the latter being built into the steining or well walls. To prevent tools, &c., falling into the water, when doing anything to the pumps, joists should be fixed and a floor laid two or three feet below the pump, as shown at F. Most of the leading pump makers supply cast-iron pump stages and shoes; one of these stages is illustrated by Fig. 42. The shoes or end pieces, G G, are built into the steining, and the stage H is bolted to them.

Fig. 43 is a view of a cast-iron roller guide for the rods to work through and also to support the rising pipe. If the rods did not have some form of guide to steady them when working up and down they would rattle very much, and any vibrating movement would tend to bend or break them, and

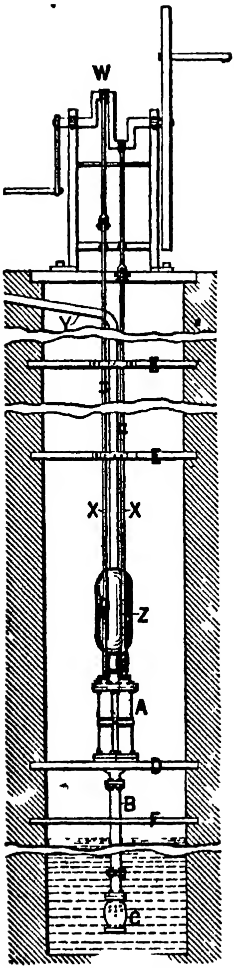

FIG. 41.

also injure the copper bucket rod or its connections to the iron rod. The rollers are made of brass or gun-metal. When made of iron they rust and do not revolve properly. When dirt or grit falls into the well, or any small pieces of earth or rock fall off the well sides, or scales of rust peel off the iron rods, the rollers sometimes get jambed, hence the necessity of fixing sheet metal capping pieces or other provisions for throwing off the pieces of grit, stone, &c. Some old well hands prefer oak stages and cleats, but they are not so good as the roller guides, as in wet wells they become soddened, and wear away to such an extent that the pump rods do not work true.

The clip I, Fig. 43, is for supporting the delivery pipe and is fixed by means of screws which should be made of copper. When the rising pipe is made of lead small flanges should be soldered on the pipe to rest on the clips, and thus avoid bruising the pipe by screwing the clips tight enough to grip it.

The strainer at C, Fig. 41, is for preventing anything being carried up with the water to injure or choke the bucket and sucker valves. Although sometimes made of iron, copper is preferable, as the sizes of the holes, or perforations, do not

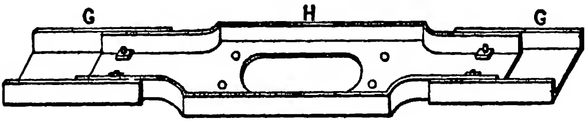

FIG. 42.

become changed by the corrosion of that metal in the same way as with iron. A 'foot valve' is sometimes fixed near the strainer. One is shown in partial section by Fig. 44. A clack valve similar to that shown by Fig. 25, but without the spur, or as shown at the bottom of the air vessel,

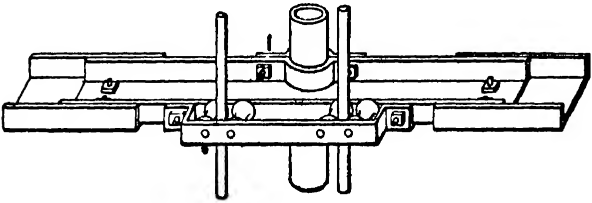

FIG. 43.

Fig. 33, is bolted between the two flanges. By some plumbers this valve is looked upon as being essential to the proper working of a pump, but this is not so. If muddy water is being raised the suction valve does not always close properly, and with the additional valve at the foot there is the

probability that the two would not be affected at the same time. In such cases the valve may be considered of advantage. And so, too, when the suction is laid horizontal and is of considerable length. With the foot valve the pipe can be filled with water, and so expedite getting useful effect out of the pump. The usual position of the valve renders it difficult of access for executing repairs. For this reason many foot valves that are fixed are never repaired and, although out of order, the pumps still answer satisfactorily. When necessary to use a foot or retaining valve, it should be fixed above the surface of the water in the well so as to be accessible for repairs. A discharge cock should be fixed just above the valve for emptying the suction pipe when necessary to do so.

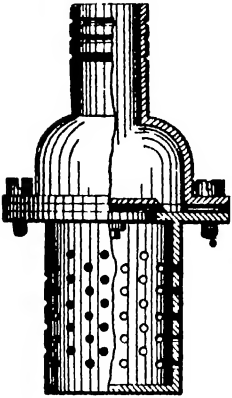

FIG. 44.

PUMP RODS AND COUPLINGS

With long lengths of pump rod it is necessary to couple them together in a simple, easy way, so that there is very little trouble in making the connections in the well or disconnecting the rods when necessary. Fig. 45, J, shows an elevation of the joint when coupled, and K with the brass socket slipped up to expose the method of dovetailing the ends of the iron rods, which are

made square in section. This coupling is very strong and, when properly fitted, cannot get out of order.

The joint of the iron to the copper rod is shown by L, Fig. 45. The loop is welded on to the iron, and the copper rod has a long screwed thread with two nuts for connecting to the loop. By this arrangement the exact length of the

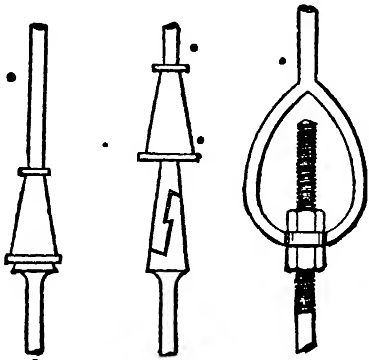

FIG. 45.

combined rods can be carefully adjusted by means of the screw nuts.

Iron well rods are made in 12 ft. lengths, and from $\frac{5}{8}$ in. to $1\frac{3}{8}$ in. in thickness, according to the size of the pumps. These vary from 2 in. to 8 in. in diameter. The copper rods are always supplied with the pumps, and their thickness is about the same as the iron rods.

SIZES OF SUCTION AND DELIVERY PIPES

The sizes of rising and suction pipes for double barrelled are the same as for single pumps. As only one barrel at a time is raising water there is no necessity for increasing the sizes of the pipes excepting for very high deliveries, or when the pumps are worked at a high speed, when friction of the water passing through them should be allowed for and larger pipes fixed. When ordinary cast-iron pipes are used the friction of the passing water is greater than with lead pipes, and in this case, too, the sizes should be increased. The following table of minimum sizes will be found useful for deep well pumps. Larger sizes could be used with advantage :—

Diameter of pump barrel	Diameter of cast-iron suction and rising main	Diameter of lead suction and rising main
2½ in.	1½ in.	1¼ in.
3 ,,	2 ,,	1½ ,,
3½ ,,	2¼ ,,	1¾ ,,
4 ,,	2½ ,,	2 ,,

GEARING FOR PUMPS

With two barrels the labour of working is slightly increased over that of a single barrel. To explain this, assume that the rods balance each other, and the man has to exercise his greatest effort when the crank that is lifting is in the middle of its stroke, that is, when it is horizontal. The other crank is also horizontal, but is travelling

downwards. When the latter crank and its load is rising, the man has to again use extra effort, and this extra effort occurs twice during one revolution of the cranks. With a single pump this happens only once.

As there are limits to a man's strength, it becomes necessary at times to add to it by mechanical appliances. Hitherto we have been dealing with such appliances, but have not exhausted them in our pump problems. Whenever we vary speed, power, or work done, it is always at a gain or sacrifice of something else.

When making calculations as to the amount of work done, fixed data must be used, and these data must be based on an average of experiments. Dealing with a man's power of carrying loads, a man can bear about 300 lbs. weight for a short time when standing still, but he could not carry it any distance. If the load was reduced to 200 lbs. he could carry it a short distance on the level, and if it was further reduced to 100 lbs. he could carry it double the distance. Time, too, has to be taken into consideration. A given amount of work can be done in a given time, but double the time is necessary to do twice the amount of work.

The standard of power for moving machinery is based on the average strength and endurance of a horse. What is known as a horse-power is represented by the power required to raise a weight of 33,000 lbs. to a height of one foot in one minute. But if 3,300 lbs. were lifted ten feet high in one minute, or the same weight was raised one foot in one-tenth of a minute, the result would be considered equal to one horse-power.

The strength of a man working at a winch is

calculated on similar lines. With an ordinary winch pump of a given size he can raise a certain quantity of water to a certain height in a certain time, but if he has to raise a larger quantity, the time must be increased or the height reduced, as his strength is a constant that cannot be varied except by using mechanical appliances.

If water has to be pumped to a height which

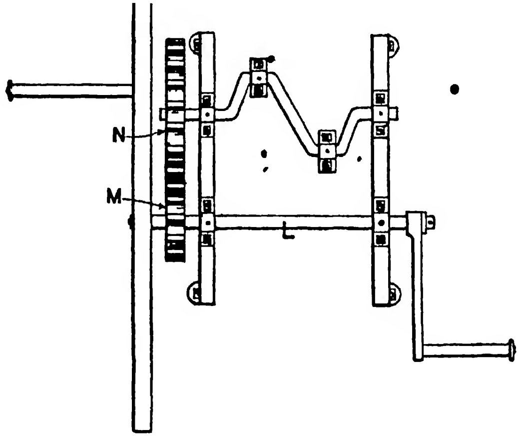

FIG. 46.

requires strength beyond that of an average man when working at a winch, what is known as a 'wheel and pinion' motion can be attached. This increases the applied power, but lowers the speed of the pumps. The man exercises his average strength and turns the wheel the same number of revolutions in the same time, but the crank which actuates the pump rod turns only half or one third the times of the wheel, according as the

gearing is in the proportion of two to one or three to one.

Fig. 46 represents a plan of a pump-frame with wheel and pinion motion. The fly-wheel and handles are mounted on the shaft L, and at M is a small cog-wheel, which turns the larger wheel N. If the number of cogs in the small wheel is 10 and the larger one 20 the power is doubled, but the speed at which the crank shaft revolves is only half that of the fly-wheel. If the large wheel had three times the number of cogs of the small one, the power would be increased three times, but only one third the quantity of water would be raised in the time an ordinary direct-acting pump would do the work. And so on for other rates of gearing.

An example of a geared pump can be dealt with. Assume a pair of 3 in. pumps with gearing 20 to 10 (or 2 to 1) to raise water to a height of 200 ft., the distances of crank and handle from centre of shaft being 5 in. and 18 in. respectively.

Then $3^2 \times \cdot 34 \times 200 = 612$ lbs. net weight of water to be lifted, to which should be added an allowance for friction of the moving parts of the pump.

To find the power to be applied to the winch the rule is :—

$$P = \frac{C \times W}{L}$$

When P = the man's power.
C = length of crank.
L = distance of handle from centre of shaft × rate of gearing.
W = weight or load to be lifted.

$$\text{Then } P = \frac{5 \text{ in.} \times 612 \text{ lbs.}}{18 \times 2} = 85 \text{ lbs.}$$

Or if the gearing is three to one

$$P = \frac{5 \text{ in.} \times 612}{18 \times 3} = 57 \text{ lbs. nearly.}$$

These are far above an ordinary man's capabilities for continuous work, and if the results are divided by 30 lbs., which we have before assumed as a fair value for a man's power, we get 3 and 2 approximately as being the number of men required to work the pump under each of the given conditions To these may be added, in each case, one additional man for labour absorbed by friction and to provide for an excess of power over load or work to be done.

By another rule can be found the size of the pump that one man could work under the given head of 200 ft. and 2 to 1 gearing, the crank and handle being 5 in. and 18 in. as before. The rule is :—

$$D = \sqrt{\left(\frac{L \times 2 \times P}{C \times 34 \times H}\right)}$$

Where D = diameter of pump barrel in inches.
L = distance of handle from crank shaft.
2 = rate of gearing.
P = man's power = 30 lbs
C = length of crank in inches.
·34 = weight of water in 1 ft. of 1 in. pipe.
H = height to be lifted in feet.

Then

$$D=\sqrt{\left(\frac{18\times 2\times 30}{5\times \cdot 34\times 200}\right)}=1\cdot 8 \text{ in. nearly.}$$

With a pump of this diameter the power and load are in equilibrium. To have an advantage of power over load the pump should be smaller than that worked out, especially bearing in mind that no allowance has been made for friction of working parts and of the water in the pipes.

The assumed height of 200 ft. may seem extraordinary, but there are numbers of wells which are that depth, and in some parts of the country they are even deeper.

In practice it is found necessary at times to have double-handled winches, as shown by Fig. 46, so that three or four men can work at the same time. In such cases it is difficult for each man to exert his power in unison with the others, and the value of 30 lbs. per man should be considerably reduced. For large pumps and very deep wells it is necessary to employ horse, steam, or other power, instead of men. This will be referred to at a future time.

A few examples of quantity of water raised by deep well double barrelled pumps can be worked.

Example 1.—How much water is raised in one hour by a pair of 4 in. winch pumps with 12 in. strokes, worked at the rate of 25 per minute?

Then

$$4^2\times \cdot 034\times 1\times 25\times 60\times 2=1632 \text{ gallons}$$

Example 2.—How long would it take with the last pump to raise 20,000 gallons?

Then

$$\left(\frac{20{,}000}{\cdot034 \times 4^2 \times 2 \times 25 \times 60}\right) = 12 \text{ hours } 15 \text{ minutes.}$$

Example 3.—What size pumps would be necessary to raise 930 gallons in one hour, the other details being as in previous questions?

Then $930 \div 2 = 465$ gallons raised by each barrel, and

$$D = \sqrt{\left(\frac{465}{\cdot034 \times 25 \times 60 \times 1}\right)} = 3\cdot0 \text{ inches.}$$

Example 4.—With a pair of 4 in. winch pumps geared 2 to 1, how much water would be raised in one hour, with a 12 in. stroke, the fly-wheel revolving 25 times per minute?

With this gearing the cranks revolve and the pumps work at half the speed of the fly-wheel.

Then

$$\left(\frac{4^2 \times \cdot034 \times 1 \times 25 \times 60 \times 2}{2}\right) = 816 \text{ gallons.}$$

Example 5.—How long would it take a pair of 4 in. pumps with 10 in. stroke, geared 3 to 1, to raise 1000 gallons, the fly-wheel being turned at the rate of 25 times per minute?

Then

$$\left(\frac{1000 \times 3}{\cdot034 \times \frac{10}{12} \times 4^2 \times 2 \times 25 \times 60}\right) = 2\cdot206 \text{ hours.}$$

CHAPTER XI

TREBLE BARREL PUMPS

Pumps with three barrels are chiefly used for raising large quantities of water. The power required for working them is a little more than for double pumps, and has to be applied more evenly. That is, the power must be constant as, no matter in what position the handles may be, one of the cranks is always rising and water is being lifted or forced up the delivery pipe. Fig. 47 is a side view of a 'three-throw' crank with the ends of the pump rods attached. Assume that the revolutions are in the direction of the arrow, the crank O is on the point of commencing its upward travel and begins to lift water before P is immediately over the shaft, until which time it also is doing effectual work. Q is travelling downwards, and on arriving at the position O will then commence to do effectual duty. By a careful study of the figure it will be noticed that the worker has to

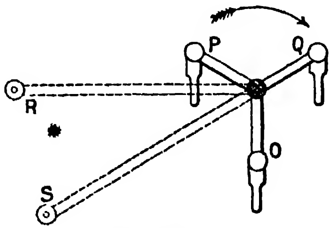

FIG. 47.

apply his power during the whole of the revolution, and not vary it quite so much as when working single and double pumps. Neither does it make much difference as to the relative angle formed by the handle with the cranks. When the handle is at an angle with the cranks, as shown at R, the load is a little less than when the handle is in a line with one of the cranks as at S. When a crank is horizontal it is further from the centre of gravity, hence the weight or load is greater at that instant of time than when in any other position. And this occurs three times during one revolution of the crank shaft.

With a heavy fly-wheel, and worked at a fair speed, the difference in amount of applied power would not be noticed by the worker. But if turned very slowly the man would find that as each rising crank arrived at a horizontal position he would have to exercise a slightly greater effort. Not effort suddenly applied, but gradually increasing as the crank rises to a horizontal position, and diminishing as it approaches the centre of gravity, which is immediately over the shaft.

For raising water with a 'three-throw' pump to a moderate height, and with small size barrels, one man can work it. But for deep well work gearing is necessary, as was explained for 'double-throw' pumps.

When three-throw pumps are being worked the water is always in motion, both in the suction and delivery pipes. The motion is not quite constant, but varies according to the position of the cranks. That is, the speed of the buckets increases as the cranks approach the horizontal, and diminishes as they pass above it. The speed of

the water in the pipes is in proportion to that of the upward travelling bucket. From what has been explained it may be assumed that air vessels are not so necessary for treble barrel pumps as for those with double and single barrels. Large numbers of three-throw pumps are fixed without air vessels or chambers.

The sizes of the air vessels for all kinds of pumps are varied according to the height the water has to be raised. For the kind of pumps usually fixed by plumbers they are from about four to ten times the capacity of one barrel.

The positions in which treble pumps are fixed are governed by the same rules as the others that have been described, and it is unnecessary to repeat what has been before stated.

As an aid to understanding the duty performed by treble barrel pumps a few examples can be worked, the rules previously given being also applicable in these cases.

Example 1.—How much water can be raised by a 4 in. three-throw pump in one hour with 12 in. stroke, the handle being worked at 20 per minute?

For one barrel we have :—

$4^2 \times {}^{\cdot}034 \times 60 \times 20 = 652{\cdot}8$ gals.

And $652{\cdot}8 \times 3 = 1958{\cdot}4$ gals. the answer.

Example 2.—How much water would have been raised if the above pumps had been geared at 2 to 1?

Then $1958{\cdot}4 \div 2 = 979{\cdot}2$ gals.

And if geared 3 to 1?

Then $1958{\cdot}4 \div 3 = 653$ gals. nearly.

Example 3.—What size direct action three-throw pumps with 9 in. strokes, the handle worked at

25 revolutions per minute, would raise 1000 gals. in one hour?

$$\text{Then } D=\sqrt{\left(\frac{1000}{\cdot 034 \times \cdot 75 \times 25 \times 60 \times 3}\right)}=2\cdot 95,$$

or say 3 in. pumps.

In the above working:—

1000 = gallons raised.
·034 = gallons in one foot of 1 in. pipe.
·75 = length of stroke in decimal fractions of a foot.
25 = strokes per minute.
60 = minutes in one hour.
3 = number of barrels, and
D = diameters of the pumps in inches.

Example 4.—What should be the sizes of the barrels in last problem if the pump was geared 2 to 1?

As the pumps work at only half the speed they must be double the capacity.

Then $\sqrt{(\text{dia}^2 \times 2)}=D$, or the diameter sought.

Or $\sqrt{(3^2 \times 2)}=4\cdot 24$ in. or $4\frac{1}{4}$ in. nearly.

Example 5.—If the gearing were 3 to 1 the barrels would have to be larger still, and the working would then be:—

$$D=\sqrt{(3^2 \times 3)}=5\cdot 19 \text{ in. or } 5 \text{ 1-5th in. nearly.}$$

Example 6.—What size three-throw pumps would be necessary to raise 5500 gals. per hour, if 12 in. strokes and the handle worked at 25 per minute, the rate of gearing being 3 to 1?

In this case we have to consider that if the

pumps were not geared they would raise three times the quantity.

Then $D = \sqrt{\left(\frac{5500 \times 3}{\cdot 034 \times 1 \times 25 \times 60 \times 3}\right)} = 10$ in. nearly.

Force pumps will now receive attention.

CHAPTER XII

FORCE PUMPS

THE power that can be exerted by 'force pumps' is limited only by the strength of the materials used in their construction. By the aid of suitable appliances a child would have little trouble in lifting, or raising, a load of several tons. It is stated that Archimedes made the assertion that if he had a place in which to fix a fulcrum, by the aid of a lever he could lift the world. And doubtless a body equal in weight to the world could be lifted by hydraulic machinery if the latter could be made strong enough for the purpose, and a suitable base found for placing it. In an earlier lecture[1] a few examples of the power of hydraulic machinery were explained and worked out, but the methods of generating that power were not dealt with.

It will be best to first deal with simple forms of force pumps. Figs. 48 and 49 are sections of those often used by plumbers for removing obstructions in sink and other waste pipes. The only difference between them is, one has a solid plunger or piston with hemp or similar material bound round near the bottom end, and the other one has two cup leathers mounted on an iron rod. Fig. 50

[1] *Lectures to Plumbers.* Batsford.

is another form in which this kind of pump is made. This differs from the others in not having any cup leathers or similar provisions, but a stuffing box, or gland, on the top of the barrel to prevent water escaping round the piston. Sometimes the

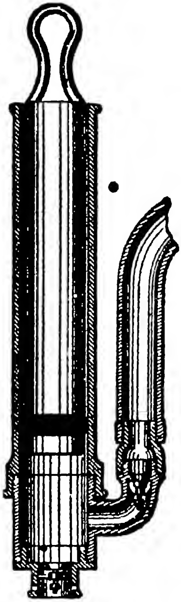
FIG. 48.

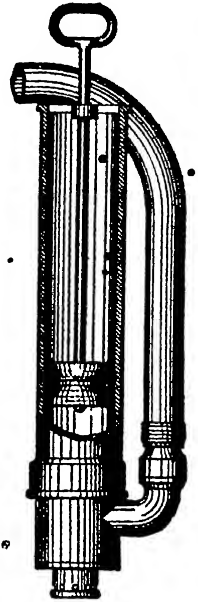
FIG. 49.

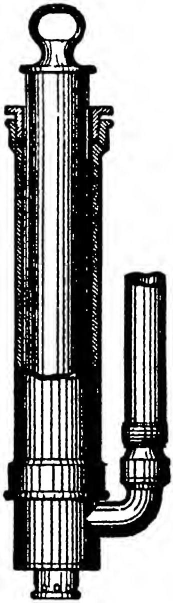
FIG. 50.

pump shown by Fig. 51 is used. This is the same as Fig. 50, but has a lever handle for working the piston, the short arm of the lever being mounted on a vibrating link fixed near the top of the barrel.

In another form, the pump has a sling and guide instead of a vibrating link.

In each pump a 'spindle' valve is fixed inside the suction end. Near the bottoms of the barrels are branches with valves inside. These valves open outwards. That is, they allow the water to escape from but not to return into the barrel. On raising the piston a vacuum is formed beneath it and the water is pushed into the barrel by the outside atmospheric pressure. On pushing the piston down the water is forced out of the barrel through the branch. The branch arm is usually temporarily attached to the end of the pipe which is to be unstopped by means of a short piece of very strong canvas or leather hose. The connection is made by inserting the end of the waste pipe into the end of the hose, and tying loosely outside with strong cord, which is then tightened by a 'twitch' or piece of wood, or a small tool such as a plumber's bolt, which is pushed under the cord, and then twisted round until the joint will resist a good water pressure when exerted inside.

The pressure per square inch exerted by the pumps Figs. 48 to 50 is calculated by the rule:— $P \div A$, in which P equals the man's power of pressing down, and A the area of the end of the piston or plunger. Assume that an ordinary man can press downwards with one hand with a power of 50 lbs., in addition to an allowance for friction of the piston in the barrel. If the pistons are 2 in. in diameter in each case, then $2^2 \times \cdot 7854 = 3 \cdot 1416$ square inches as the areas of the ends.

And $50 \div 3 \cdot 1416 = 15 \cdot 9$ lbs. as the pressure exerted per square inch inside the barrel and pipe connections. The pressure on each circular inch $= (50 \text{ lbs.} \div 2^2 =)\ 12 \cdot 5$ lbs.

To find the power to apply for the removal of an obstruction in the waste pipe we first find the area of the surface pressed against and × by the pressure per square inch exerted by the pump. As an example, if a 2 in. pipe is choked, we then have $2^2 \times \cdot 7854 \times 15 \cdot 9$ lbs. $= 49 \cdot 95$, or say 50 lbs., which is the same as was exerted by the man on the piston. If the pipe was 1 in. in diameter we then have $1^2 \times \cdot 7854 \times 15 \cdot 9 = 12 \cdot 28$ lbs., or only one quarter of the man's efforts usefully exercised in pushing against the obstruction.

When the area of the end of the piston and the area of the cross section of the waste pipe are the same the whole effort of the man is utilised, as shown by a previous working.

By the aid of the pump shown by Fig. 51 the power is considerably increased. To explain this assume that a man has a yoke on his shoulders and a pail is suspended from each end, each pail with its contents weighing 50 lbs. There being two pails of equal weight they balance each other, but the man has to support a load of 100 lbs. And so with the lever handle pump. If the man's power of 50 lbs. is exerted at C, which is the same distance as A from the fulcrum B, the total weight of the latter is 2×50 or 100 lbs., as the resistance at A balances the power at C.

If the lever is extended to D, the length from D to B being twice that from B to A, the whole of the power is increased. And 50 lbs. of pressure exerted at D would require 100 lbs. resistance at A to balance it, and $100 + 50 = 150$ lbs. as the weight resting on B. And so on for any other increase in the length of the lever.

In a previous problem it was found that the pressure exerted in removing an obstruction in a pipe was in the proportion of the area of the piston end to the diameter of the waste pipe. With the 2 in. piston and 2 in. pipe and the pump shown by Fig. 51, 50 lbs. applied at D would press against the obstruction in a 2 in. pipe with a total force of 150 lbs. But if the obstruction was in a 1 in. pipe, which is one-fourth the size, the total pressure against the obstruction would be only 37·5 lbs. And so on for any other variations.

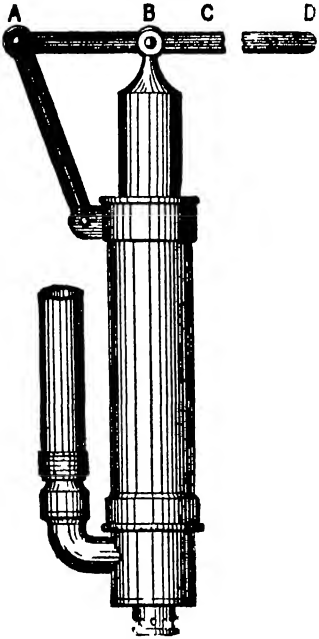

FIG. 51.

A great advantage of the force pump for removing an obstruction in a pipe is that no matter in what position the obstruction may be, even several feet or yards away, or beyond bends which would not allow a cane to pass, the same power is exerted against it as if it had been near the pump, always provided that the pipe is full of water, and not air. For practical purposes, it is generally assumed that water is not capable of being compressed or made

to occupy a lesser space when under pressure. That being so, the force exerted by a man with a pump against the object to be removed is the same as with a power applied to the end of a solid rod of any hard material when the other end of the rod is pressing against the obstruction.

CHAPTER XIII

Testing Strength of Materials by Force Pumps

The power of a force pump is utilised for testing the strength of pipes, boilers, girders, and many other fittings. Also for generating hydraulic power for moving machinery, working lifts and elevators, and many other purposes.

For testing pipes, boilers, &c., the pump is fixed in a chamber, as shown by Fig. 52. The size of the pump piston is very small, and the chamber holds only a few gallons of water. When a boiler is being tested it is first filled, and then all manholes and connections are made tight. The pipe E is then made good to the boiler and the pump worked. When the boiler is filled, no matter if it holds 10 or 1000 gallons, it has only to resist the pressure of the contained water, but if only an additional few drops, or a very small quantity more water is forced in, the internal pressure is raised to an enormous extent. To explain the increase assume that a cylinder, or cylindrical boiler, 6 ft. long by 3 ft. diameter, is being tested, and the pump has a 1 in. piston, the lengths of the short and long arms of the lever being 4 in. and 36 in. respectively, the pipe from the pump to the boiler being $\frac{1}{2}$ in.

in diameter. A larger size pipe is unnecessary as it is pressure, and not volume, of water that is required.

The area of the piston end being 1^2 in. $\times$ $\cdot 7854 = \cdot 7854$ of an inch. If a 1 lb. weight was hung on the end of the lever at F, the resistance at the other or short end would be found as follows:—

$$R = \frac{L \times W}{S}$$

Where R = the resistance of the link at the end of the short arm.
L = the length of the long arm in inches.
S = the length of the short arm in inches.
W = the weight placed on the end of the long arm.

Then

$$R = \frac{36 \text{ in.} \times 1 \text{ lb.}}{4 \text{ in.}} = 9 \text{ lbs.}$$

This is equal to 10 lbs. resting on the top of the pump piston.

The area of the piston being 1 circular inch, and the weight resting on it 10 lbs., then 10 lbs. pressure is exerted on each circular inch inside the boiler, the pressure per square inch being $10 \div \cdot 7854 = 12 \cdot 73$ lbs. A small deduction should be made for the loss by friction of the piston in the barrel, but this is partly overcome by the weight of the long arm of the lever being in excess of that of the short arm.

If a pressure of 50 lbs. was exerted at F, the resistance at G would be

$$R = \frac{36 \times 50}{4} = 450 \text{ lbs.}$$

The resistance of 450 lbs. being necessary to balance 50 lbs. at the end of the long lever, we have $450 + 50 = 500$ which $\div \cdot 7854 = 636 \cdot 62$ lbs. pressure per square inch transmitted to the boiler.

To vary the last problem we will assume that the boiler is to work under a pressure of 100 lbs., and that its ultimate breaking strength is 800 lbs. per square inch. What should be the heaviest weight placed on a pump lever at F?

The boiler should be tested, not to destruction, nor to strain and weaken it, but to a point, say six times above its working pressure, or say 600 lbs.

Then $600 \times \cdot 7854 \times 1^2$ in. $= 471 \cdot 24$ lbs. to be applied to the top of the piston. The lever is 4 in. + 36 in. = 40 in. long and in the proportion of 1 to 9, and 1-9th of the weight is hanging on the long arm and 8-9ths on the short arm.

Then $$\frac{4 \times 471 \cdot 24}{36} = 52 \cdot 36 \text{ lbs.}$$

the heaviest weight that should be applied to the lever at F.

Before going any further with force pump problems we will dwell for a short time on the strength of the materials necessary for the barrels, &c.

Taking first the pump shown by Fig. 48. It has already been found that the pressure inside the barrel is equal to $15 \cdot 9$ lbs. per square inch when the piston is pushed down with a power of 50 lbs. Assume that for a short time the power could be doubled, the pressure would also be doubled. Taking the pressure as being equal to 32 lbs. per square inch, the barrel must be strong enough to resist fracture when that force is applied. To

allow for contingencies it is usual to take the safe strength of the materials at something below their actual breaking strength. Force pump barrels are usually made of brass, and as that alloy varies very much indeed in its composition, a wide margin should be allowed, and 1-6th of its tensile strength taken for safe working. On referring to Molesworth's tables, we find the tensile strength of cast brass is 8 tons per square inch. That is, an average bar of brass, 1 in. square in section, breaks when 8 tons are suspended from it. Then 8 tons ÷ 6 = 3000 lbs. nearly as the safe working strength. If we assume that we are dealing with 1 in. in length of the pump barrel, which is 2 in. in diameter, and that the water inside is divided across the diameter by an imaginary line of cleavage, and that a force is tending to separate the water into two halves, the thrust will act on opposite sides of the barrel and exercise a tearing strain on the material at each end of the line of cleavage. The diameter of the barrel being 2 in., which × 1 in., the length we are dealing with, we have 2 square inches. And this × 32 lbs., the pressure exercised when the pump is worked = 64 lbs. tending to tear the barrel.

Then by Rule of Three

$$\therefore 3000 \text{ lbs.} : 1 \text{ in.} :: 64 \text{ lbs.} : 0{\cdot}0213 \text{ in.},$$

the thickness of the two sides of the barrel, which ÷ 2 = 0·01056 in., or less than 1-64th of an inch as the thickness of one side of the barrel to resist being torn by the applied pressure. For resisting a bursting strain this thickness would be quite sufficient, but a pump of that substance would be

liable to injury by bruising when being carried about or when allowed to lie about in the workshop. To prevent such injuries the pump should be made stronger, or about 1-16th in. thick.

The strength of the barrel for the pump shown by Fig. 52 can be found by the same rule. The diameter of the piston is 1 in. Assume the pump is to be constructed to test with a maximum

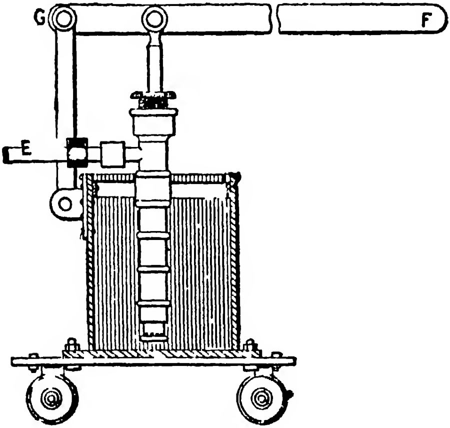

FIG. 52

pressure of 2 tons, or 4480 lbs. per square inch. To find the proper thickness for a brass barrel:—

$$\therefore 3000 \text{ lbs.} : 1 \text{ in.} \quad : 4480 \text{ lbs.} \quad 1{\cdot}493 \text{ in.}$$
$$\text{which} \div 2 = {\cdot}746,$$

or nearly $\frac{3}{4}$ in. thickness for the sides of the barrel.

For finding the thickness of the boiler, which is made of wrought iron, and has riveted seams, and is 3 ft. or 36 in. diameter. Molesworth gives an

average tensile strength per square inch of wrought iron as 22 tons. If the safe strength is taken as 1-6th the breaking strength, we have $22 \div 6 =$ $3\frac{2}{3}$rds tons, or 8213 lbs., as the safe strength of the iron plate. If the boiler has to work under a pressure of 100 lbs., we have 100×36 in. $=$ 3600 lbs. tending to tear the sides.

$\therefore$ 8213 lbs. : 1 in. : : 3600 lbs. : 0·438 in. which $\div\ 2 =$ 0·219 in., or a thickness of a little over 1-5th of an inch. And this is the minimum thickness for the iron plate for making a boiler to work under the assumed conditions. As the

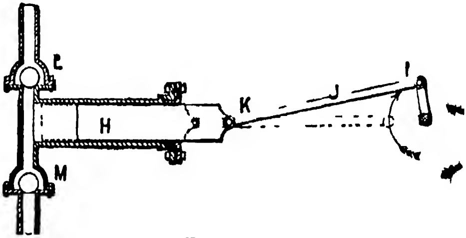

FIG 53.

boiler plates are weakened by rusting, also by the rivet holes, a further allowance should be made for this, and in practice double the above thickness would be used under the given conditions.

The force pumps hitherto dealt with have worked vertically, but it is not essential that they should do so. A great many force pumps used for raising water are fixed horizontally.

The section, Fig. 53, is an example in which the piston H is worked directly from the crank shaft I by the connecting rod J, which works on a joint at K. L and M are valves on the delivery

and suction pipes. The quantity of water raised at each stroke is equal to the cross section of the piston × the length it is drawn out of the barrel. Assuming that the piston is 3 in. diameter and travels in the barrel 9 in. The solid contents of the piston being 3^2 in. × ·7854 × 9 in. = 63·6174 cubic inches. And as 1728 cubic inches : $6\frac{1}{4}$ gals. : : 63·6174 cubic inches : ·23 gals. The barrel may be 4 in., or any other diameter larger than the piston, but the quantity of water raised at each stroke is equal only to the volume of the piston.

To prevent the piston 'rocking' in the barrel

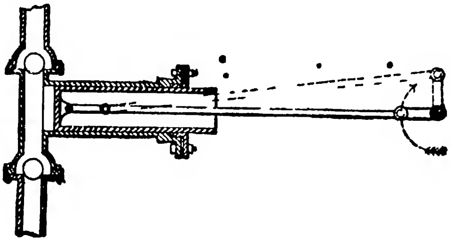

FIG 54.

it is sometimes necessary to have a guide to give it a parallel motion. With the same object in view, force pumps are made as shown in section by Fig. 54. The piston is hollow and the coupling rod connected to the bottom, or inner end, as shown in the figure. In this case the size of the piston governs the 'throw' of the crank. If the latter is too large the coupling rod knocks against the inside of the piston, as shown by the dotted lines, during the revolution of the crank.

Both the foregoing pumps can have double or treble barrels and can be worked from the same

crank shaft, as was described for ordinary lift pumps. The manual power to work them is found by previous rules.

A great many force pumps are worked by the direct action of horse, or steam, or water power, but these will be referred to later on.

LIFT AND FORCE PUMPS

The principles of lift and force pumps are explained by Fig. 55. In the figure O is the barrel, P the piston with double cup leathers, Q the suction pipe, R the delivery, S S′ the suction valves opening inwards, and T T′ the delivery valves opening outwards. When the piston is rising the valves S′ and T open and S and T′ close. When the piston is travelling downwards S and T′ open and S′ and T close, the water being pushed up by atmospheric pressure into the barrel or cylinder and lifted out of the upper, and forced out of the lower, portion by the power applied to the pump.

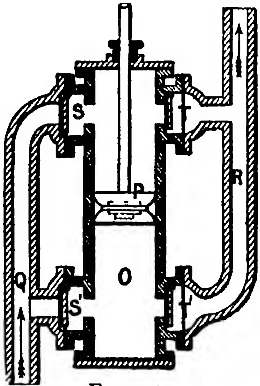

FIG. 55.

Fig. 56 is a section of one pump out of a great many that have been patented for use by manual or hand power. Fig. 57 is a cross section of the barrel. In pumps of this description it is usual to call the suction and delivery valves 'ports.' In the drawing the piston is shown working in a

barrel, U, and outside this barrel is a second one enclosing an annular space, V, with divisions running the whole length on opposite sides of the barrel. When the piston is rising water enters the port W, and that above the piston is lifted through X. When the action is reversed water enters at Y, and is forced through Z. A copper air vessel, A, has stuffing boxes at B B, through which the bucket rod C works. The suction D is connected to the well or other water to be raised, and the delivery pipe is connected to the air vessel at E.

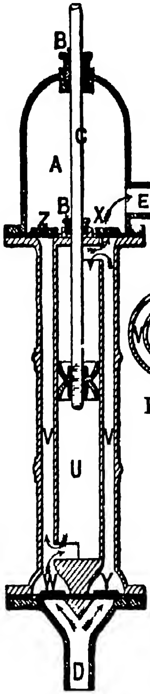

FIG. 56.

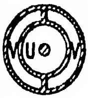

FIG. 57

When a lever handle is used this pump is harder to work than ordinary lift pumps, owing to the friction of the bucket rod in the two stuffing boxes, and also by having to use as much effort when raising the handle as when pulling it down. For these reasons it is advantageous to work this pump with a winch on frame. As much water is raised by this pump as with an ordinary double-barrelled pump, the diameters of the working barrels and length of stroke being equal in each case.

POWER FOR WORKING PUMPS

The powers for working pumps are man, donkey, horse, steam, gas, water and electric. Their relative values are based on the average strength and endurance of a horse. This, for engineering purposes, is assumed to be equal to a load or weight of 33,000 lbs. lifted 1 ft. high in one minute. If 33 lbs. were lifted 1000 ft. high in one minute or 330 lbs. were lifted 100 ft. in the same time, it would be considered as 1 h.p. And again, if 3300 lbs. were lifted 1 ft. in $\frac{1}{10}$th of a minute, or 33,000 lbs. were raised $\frac{1}{10}$th of a foot in $\frac{1}{10}$th of a minute, the work done would still be considered as equal to 1 h.p. Hence the unit of power is called one horse. Multiples and fractions of the same all bear some proportion to the unit above expressed. To compare a man's power to that of a horse a problem can be taken of a man working at a 4 in. jack pump with 12 in. stroke at the rate of 30 strokes per minute, and raising the water to the height of the nozzle from a depth of 25 ft.

Then 4^2 in. $\times 1 \times \cdot 34 \times 30 \times 25 = 4080$ foot-pounds of work done per minute, and $4080 \div 33{,}000 = \cdot 1236$ horse-power, or h.p. The power exerted by the man in this case would be considered as $\frac{1}{8}$th h.p.

Taking another example of a man working a lift pump. Let the pump have 3 in. double barrels with 1 ft. stroke, geared 2 to 1 to raise water 50 ft. high, the revolutions of the fly-wheel being 25 per minute. Then

$$\frac{3^2 \times 2 \times \cdot 34 \times 50 \times 25}{2} = 3825 \text{ foot-lbs. of work done.}$$

And 3825 ÷ 33,000 = ·116 h.p. And this shows the power of the man actually exercised at the winch pump, under the above conditions, to be a little less than $\frac{1}{8}$th horse-power. If double the quantity of water was raised to half the height in

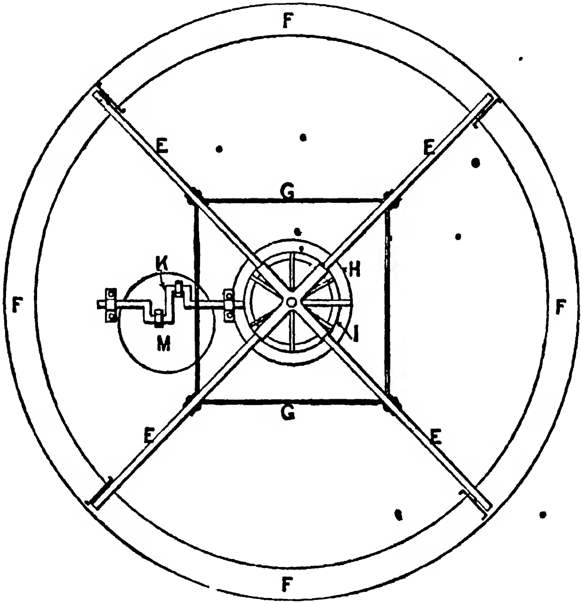

Fig. 58.

the same time, or half the quantity was lifted to twice the height in one minute, the proportion of work done would be considered as $\frac{1}{8}$th of the unit or standard of work.

In many cases the power of a number of men

is utilised for pumping by having a capstan and shafts, as shown on plan by Fig. 58, and elevation, Fig. 59. In the illustrations E E are the shafts pushed round by the men walking in the track, F F. G G are the tie rods from shaft to shaft, H is the frame to support the capstan, and the large cog-wheel I. The cogs of the latter are on the under side, and are toothed into a smaller wheel, J, fixed on the crank shaft, K, from which hang the rods, L, to actuate the pumps fixed in the well M. Fig. 59 is a side view or elevation of the same

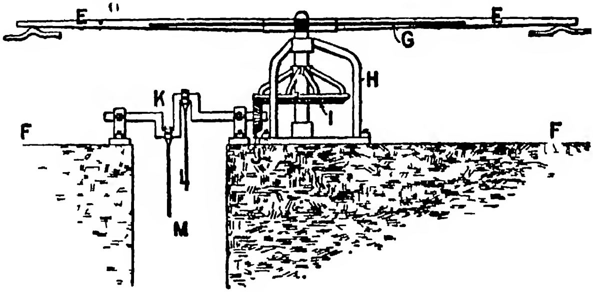

FIG. 59.

engine. The reference letters are the same in both illustrations. To find the power or number of men to work the pumps some data to work from must be assumed.

Assuming the pumps to be 4 in. double barrelled with 9 in. strokes, the centre of the track the man or men walk in 20 ft. in diameter, the applied power being 10 ft. from the centre of the capstan, which is turned three times per minute. The large wheel is 3 ft. and the small wheel 6 in. in diameter, the centres of the cranks being

$4\frac{1}{2}$ in. from the centre of the crank shaft, and the water is to be raised to a height of 100 ft.

To find the work to be done the rule is :—

$$W = H \times d \times \cdot 34 \times R \times N \times L.$$

Where W = work to be done.
H = height in feet the water is to be raised.
d = diameter of barrel in inches.
·34 = weight of water in 1 ft. of 1 in. pipe.
R = revolutions of crank shaft per minute.
N = number of barrels.
L = length of stroke.

If $H = 100$ ft., $d = 4$ in., $R = \frac{36 \times 3}{6} = 18$, and $L = 9$ in. $= \cdot 75$ ft.

Then $W = 100 \times 16 \times \cdot 34 \times 18 \times 2 \times \cdot 75 = 14{,}688$ foot-pounds per minute.

As pump gearing is generally in a position where moisture or dust and dirt is present, a great deal of the applied power is absorbed by friction caused by rust and grit.

If we assume this friction and excess of power over load consumes $\frac{1}{3}$rd the power exerted, we then have $14{,}688 + \frac{14{,}688}{3} = 19{,}584$ foot-pounds of work to be done per minute. And $\frac{19{,}584}{33{,}000} = 0 \cdot 59$ h.p., or horse-power, required to do the work.

If we further assume that by the gearing shown by Figs. 58 and 59 a man's power is 1-6th that of a horse; then 1-6th = ·166.

And as ·166 : 1 :: ·59 : 3·5

Thus showing that the power of $3\frac{1}{2}$ men is

necessary to raise the water under the given conditions.

With regard to the power obtained by the gearing the working of the problem is based on the principles of compound levers.

The crank and small cog-wheel have radii of $4\frac{1}{2}$ in. and 3 in. respectively. The heaviest load is when the crank is horizontal, and $= 4^2 \times \cdot 34 \times 100 = 544$ lbs.

The length of the lever, represented by the length of the crank, being $4\frac{1}{2}$ in., we have $544 \times 4\frac{1}{2} = 2448$ in.-lbs. hanging on the crank. To raise this the power to be applied to the small cog-wheel is found by dividing the above inch-lbs. by the radius of the latter. And $2448 \div 3 = 816$ lbs.

This power is derived from the horse or men at the end of the shaft, which is 10 ft., or 120 in., long, acting on the large cog-wheel, whose radius is 18 in.

Then $120 \div 18 = 6{\cdot}66$.

And $816 \div 6{\cdot}66 = 122{\cdot}5$ lbs., to which should be added one third for friction.

$\therefore$ $122{\cdot}5 + (\text{1-3rd or } 40{\cdot}8) = 163{\cdot}3$ lbs. of pressure to be applied to the end of the driving shaft.

Stated concisely, the power to be applied equals:—

$$\frac{4^2 \times \cdot 34 \times 100 \times 4{\cdot}5 \times 18 \times 4}{3 \times 120 \times 3} = 163{\cdot}3 \text{ lbs.}$$

If this were divided by the number of men we have

$163{\cdot}3 \div 3{\cdot}5 = 46{\cdot}6$ lbs. of pulling or pushing pressure exerted by each man at the shaft.

For long and continuous work a number of

men would not average the above pressure individually, and in calculations for pumping with a capstan and shafts or levers, a man should not be valued higher than 1-10th of a horse. In the last problem the power required was ·59 of that of a horse, and ·59 × 10 gives 5·9, or say six men to do the work, the individual efforts of the men being = 163·3 ÷ 6 = 27·2 lbs. pressure exerted by each man on the shafts.

With regard to the power of animals, although that of a horse is usually taken as being able to raise 33,000 lbs. one foot high in one minute, as before stated, it is only half that, or 16,500 lbs. A pony or donkey is usually assumed to have half the power of a horse, but such animals do not weigh nearly or half as much as a horse, and they should not be rated at more than ¼ horse-power. Bullocks are about as strong as horses but slower in speed.

Other powers such as steam, gas, water and electricity, hot-air and petroleum engines are also applied to pumping water.

Steam is utilised in several ways. A common one is to use an ordinary engine with a rigger or pulley wheel fixed on the end of the crank shaft. From this wheel a belt, or driving strap, passes round a similar rigger on the end of the pump crank shaft. The rigger is instead of the winch handle on the left side of Fig. 41. The sizes of the wheels are regulated in proportion to the speed of the engine and the rate it is desired the pumps are to work.

Another method is to work the pumps by 'direct-action' of steam. The principle is explained by Fig. 60, in which N is the pump, O the

steam cylinder, and P the steam ports which are opened and closed by the sliding valve. The pumps are usually in pairs and the pistons are connected by rods or shafts, Q. By this arrangement the steam pressure is transmitted directly to the water in the pumps, and forces it into the delivery pipe. The air vessel, R, is for preventing shock in the pipes by keeping the water in motion between the strokes of the pistons.

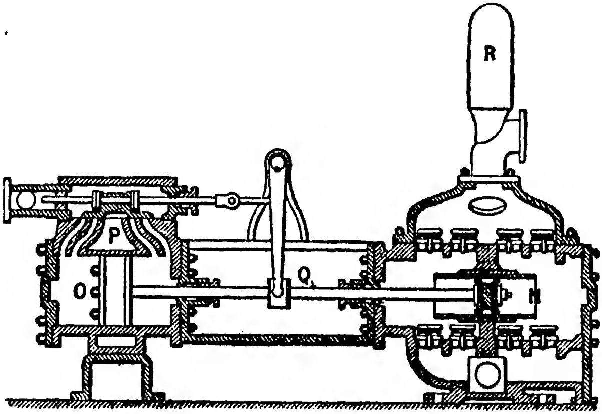

FIG. 60.

Fig. 61 is a 'Beam Engine.' The beam, S, rocks on an axis, or trunnions, in the centre, and the motion is caused by the steam in the cylinder, T, the force being transmitted to the pump, U, or to a crank shaft and fly-wheel for working two or more pumps. The connecting rods to the steam and pump pistons have joints and guides, not shown in the figure, to give them a parallel motion.

Gas engines are worked by exploding a mixture of coal gas and atmospheric air in a cylinder. The sudden expansion of the exploded gas causes a piston to move in a cylinder, and the force of the explosion is transmitted by means of a pulley on a crank shaft and a belt to a pulley or rigger on the pump shaft. The shock of the explosion is steadied, and a continuous motion obtained by means of a rather heavy fly-wheel, mounted on the same shaft as the driving pulley and piston connection.

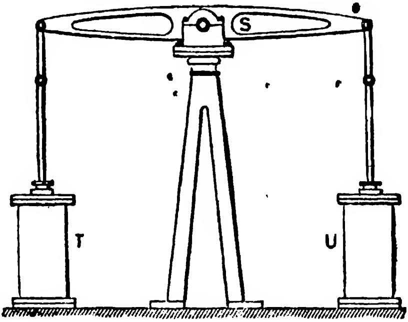

FIG. 61.

'Hot-air' engines are worked by the alternate expansion and contraction, by heating and cooling, of a volume of air in a cylinder heated by coke or other fuel. The pumps are usually worked directly from the engine, but pulleys and belting can be used.

'Petroleum engines' are worked by exploding the vapour of that oil mixed with air, much in the same way as with gas engines. When these engines are used they should be fixed some

distance from the well or reservoir, and care taken that none of the fuel is spilt or allowed to get into the water.

Gas, hot-air and petroleum engines are all very useful for small pumping stations, such as are usually constructed for supplying mansions, farmsteads, and villages, and do not require any extraordinary amount of attention.

'Water power' is much used for pumping both on a large and a small scale, and is applied in many ways. There are several kinds of 'Hydraulic engines.' Figs. 60 and 61, when made especially for working with water instead of with steam, are capable of exerting great power.

Hydraulic rams and double-action, or pumping, rams are doing excellent work in all parts of the country where there are streams or springs of water. Such appliances are dealt with in a separate treatise.[1]

Water wheels are another power for raising water. As these machines come under the heading of hydraulics we will here deal with them.

[1] *Hydraulic Rams, their Principles and Construction.* Batsford. 2*s.*

CHAPTER XIV

WATER WHEELS

OF all the mechanical powers that are utilised for pumping none are of more interest to plumbers

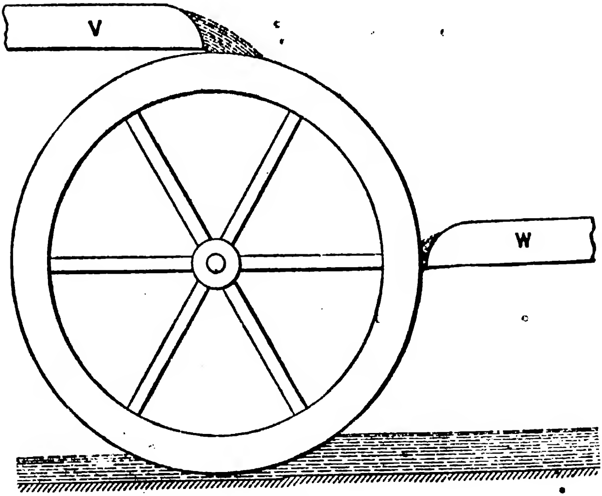

FIG. 62.

than water wheels. Although not made by such workmen they are used in many places, and

plumbers frequently have to fix the pumps and pipes in connection with them. In distant country places the wheels are often made by the estate, or village, carpenters or blacksmiths, and it is necessary that the plumber should have some knowledge of their power and working, so as to be able to give advice when called upon to do so, or make repairs when necessary.

Wheels are divided into three classes. Fig. 62 is drawn to enable the student to distinguish them. When the water is discharged on to the top of the wheel, as at V, it is known as an 'Overshot wheel,' when in the centre, as at W, a 'Breast wheel,' and when the stream runs beneath, it is known as an 'Undershot wheel.' The sides of the rims of the wheels are known as 'Shrouds.' The rims of the first two kinds are divided into curved compartments for holding water, and these are called 'Buckets.' The divisions in Undershot wheels are straight instead of curved, and parallel to the spokes or radii. These divisions are known as 'Floats.'

OVERSHOT WHEELS

Fig. 63 is a diagrammatic side and edge view of an Overshot wheel, in which X is a crank attached to the axle; Y, the pump, with barrel similar to Fig. 54, but the suction and delivery valves different; and Z, the air vessel and delivery valve. With such wheels the gravity or weight of the water is the motive power, and has the same influence on the perimeter of the wheel as a weight on the long arm of a lever. Hence to find the power of a water wheel the quantity or weight of

the water retained in the buckets has to be known, and also the length of the series of levers represented by the lengths of the spokes, or, to be more exact, the horizontal distance from the centre of the crank shaft to the centres of the buckets. The size of the latter and the distance between the shrouds should also be known, so that their holding capacities may be calculated.

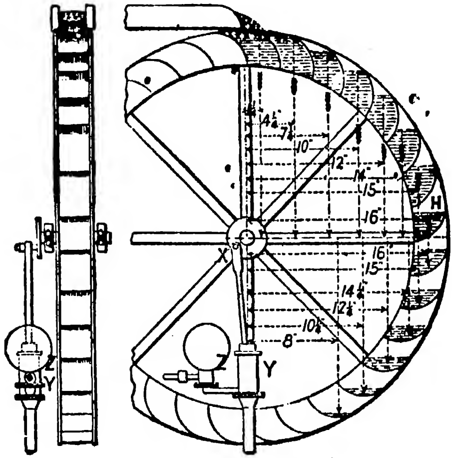

FIG. 63.

As far as possible the flow of water should be regulated to the size and speed of the wheel. If not so regulated a great deal of water is wasted by the wheel revolving so slowly that the buckets fill to overflowing, or the revolutions of the wheel are so quick that the buckets do not fill properly, as the water splashes outside. The width of the mouths of the troughs or buckets, or their distance

apart, has also to be regulated so that they fill evenly and without shock.

Fig. 63 is a sketch of one of the smallest wheels the writer ever had to do with, and is drawn from memory. The pump had a $1\frac{1}{2}$ in. barrel, with a 4 in. stroke, the suction and rising main being $\frac{3}{4}$ in. The diameter of the wheel was 36 in., and the length of buckets (or distance between the shrouds) 3 in. The available quantity of water was about 70 gals. per minute, and the height to which the water was pumped was about 50 ft. In the figure are broken lines drawn vertically from the loaded buckets to the horizontal spoke, with arrows showing the direction of the pressure caused by gravity. It will be noticed that no two buckets are the same horizontal distance from the axis, and neither do any two hold the same quantity of water. To find the exact power of the wheel would be a tedious task, as the contents, or weight, in each bucket would have to be calculated and the distance from the axle measured. But an approximation can be arrived at, and this will answer our purpose. If we take it that the buckets are 3 in. wide, and the depth from the face to the 'sole-boards,' or bottom nearest the axle, 3 in., the bucket shown at H would very nearly have the capacity of one fourth of a 6 in. pipe.

Then 6 in. × 6 in. × ·34 = 12·24 lbs. of water in one foot of 6 in. pipe.

12·24 ÷ 4 = 3·06 lbs. in 3 in. of the pipe, and 3·06 ÷ 4 = 0·76 lbs. weight in the bucket H. If we assume that the weights in the buckets above H gradually increase at the rate of ·12 lbs., and those below, that retain water, decrease in the

same proportion, we have one datum to work from. The other data can be measured from a scale drawing, or the distances can be taken as figured on the illustration, Fig. 63.

By a rough calculation the weight of water in the buckets is found to be about 11·48 lbs., which × the horizontal distance from the centre of the axle the total weight pressing on the horizontal lever, represented by the spoke opposite bucket H, is equal to 110·73 inch-pounds.

Assuming that the size of the pump was unknown, and it was necessary to find what size pump the wheel would work, after allowing one fourth of the power as being absorbed by friction, the rule would be :—

$$D = \sqrt{\frac{P \times \cdot 75}{C \times \cdot 34 \times h}}$$

In which D = the diameter of the pump.
P = power of wheel.
C = length of pump crank.
·34 = weight of water in 1 ft. of 1 in. pipe.
h = height to which water is raised by pump.

$$\text{Then } D = \sqrt{\frac{110 \cdot 73 \times \cdot 75}{2 \times \cdot 34 \times 50}} = \frac{3 \cdot 3219}{1 \cdot 36} =$$

2·44 and $\sqrt{2 \cdot 44} = 1 \cdot 56$, or a little over $1\frac{1}{2}$ in. the diameter of the pump barrel. The same wheel would work a $1\frac{1}{2}$ in. double-action or double-barrel pump, and the motion would be more even than with a single barrel.

To find the quantity of water raised by the pump the rule is :—

$$g = D^2 \times \cdot 034 \times 20 \times L.$$

Where g = gallons of water raised per minute.
D = diameter of barrel in inches.
·034 = gallons in 1 ft. of 1 in. pipe.
20 = strokes per minute.
L = length of stroke.

Then $g = 1 \cdot 56^2 \times \cdot 034 \times 20 \times \frac{4}{12} = \cdot 5516$ gals. per minute, which $\times\ 60 = 33$ gals. per hour or 792 per day. If a double-barrel pump was used the latter quantity would be doubled.

When the power of a wheel is calculated to its utmost capacity, it follows that the water supply must be equal to the work to be done. To find the quantity necessary to drive the wheel, we may assume that the periphery is filled 20 times per minute.

To find the contents, we first calculate what the whole wheel would hold, and then deduct the centre portion. Then $3^2 \times 4 \cdot 9 = 44 \cdot 1$ gals. And $2 \cdot 5^2 \times 4 \cdot 9 = 30 \cdot 6$ and $44 \cdot 1 - 30 \cdot 6 = 13 \cdot 5$, which $\div\ 4 = 3 \cdot 37$ gallons, the holding capacity if the whole of the buckets were filled to the outer edge of the shrouds. As the wheel revolves 20 times per minute, we have $3 \cdot 37 \times 20 = 67 \cdot 5$ nearly gals. required per minute. The water should flow at a little higher speed than the wheel, but the above quantity is sufficient as the speed of the former increases to a slight extent when leaving the trough, as friction then ceases to exercise a retarding influence on the flow.

The width of the trough should be less than the wheel, so that the water shall not splash outside the latter. The depth of the water a few inches back from the outlet, assuming the trough

to be $2\frac{1}{2}$ in. wide, would be found as follows: Diameter of wheel $\times$ 3·1416 $\times$ 20 = 188·5 nearly feet per minute lineal velocity.

Then 67·5 gallons = 10·8 cubic feet, or 18,662·4 cubic inches of water per minute.

188·5 ft. = 2262 lineal inches, representing the velocity of flow per minute.

And $\frac{18{,}662\cdot4}{2262 \times 2\cdot5} = 3\cdot3$ inches, the depth of the water in the trough.

If the water had a fall of a few inches on to the wheel a thinner, or shallower, stream would answer the purpose, as additional power would be gained from the impulse of the falling water. Too much fall should not be given, as this would cause shock and excessive splashing.

For effective duty done by the pump we may assume that the water falls a distance of half the diameter of the wheel, or say 1·5 ft. The amount used per minute being 67·5 gallons or 675 lbs., we have 675 $\times$ 1·5 = 1012·5 foot-pounds, from which deduct $\frac{1}{3}$rd as being absorbed by friction = 1012·5 − 337·5 = 675 foot-pounds effective power per minute.

The quantity raised being ·5516 gallons or 5·516 lbs., and the height to which the water is raised 50 ft., then 5·516 $\times$ 50 = 275·8 foot-pounds of work done per minute.

And for the percentage of work done by the wheel:—

As 675 : 100 : : 275·8 : 40·86 nearly.

The speed of 20 revolutions of the wheel or 20 strokes of the pump per minute should not

be exceeded, or the pump would soon wear out. If it is necessary for the wheel to run at a higher speed a small pinion could be attached to the axis of the wheel at X, Fig. 63, and this geared to a larger cog-wheel fixed on the end of a crank shaft to work one, two, or three pumps.

With regard to the power of large size overshot wheels, the principles already laid down apply to them also. In general terms it may be stated that the greater the diameter of the wheel the further the weight (water) is removed from the centre of gravity, or the greater the distance from the axis, measured on a horizontal line, the greater the power. And the longer the distance between the shrouds the greater the holding capacity of the buckets. This again adds to the power in the same way as placing a larger weight on the long arm of a lever would increase the power of that appliance.

It is far better to increase the length of the buckets than their depth. With deep buckets the weight of the water is nearer to the centre of gravity, which reduces the power of the wheel, and neither do deep buckets fill to advantage. A thick or deep stream of water on the wheel is not nearly so good as a thin one, and for that reason the small wheel which we took as a text for explaining certain principles should not be accepted as a model. It would have been much better if the buckets had been shallower and two or three times the length, and the power water fed out of a channel or trough about twice or three times the width. The stream would then have been about one half or one third the depth.

With very large wheels the weight on the

periphery or rim is very great, and when the pump cranks or other machinery are turned by, or geared to, the axle, the strain on the spokes is a serious matter. To avoid this strain some wheels have cogs inside the bucket rim, which actuate a small wheel or pinion, as shown by Fig. 64, fixed on the end of the pump crank shaft. The speed of such a wheel should be very slow when used for pumping, otherwise the pumps

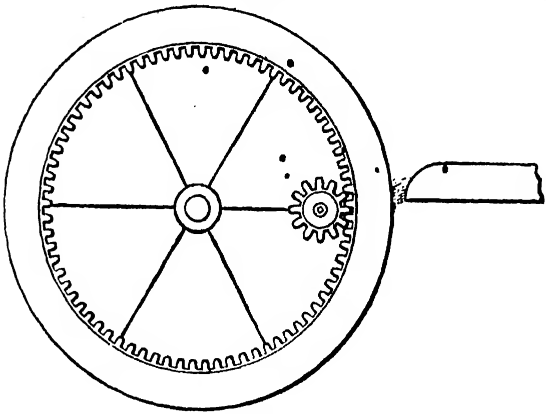

FIG. 64.

would soon wear out. If the speed is, say, four revolutions per minute, and the diameter of the pinion one sixth of the wheel, the proportion is one to six, the small one revolving six times to the other's once, so that the pumps would make 24 strokes per minute. Should the speed be higher than that given it would be necessary to gear another shaft with cog-wheels of properly proportioned sizes for actuating the crank at the

speed best suited to the pump's capacity for working. By additional gearing the friction is increased, and an allowance should be made for this when calculating the power.

BREAST WHEELS.

Fig. 65 is a 'Breast' wheel in which the feed water enters the buckets at or near the centre.

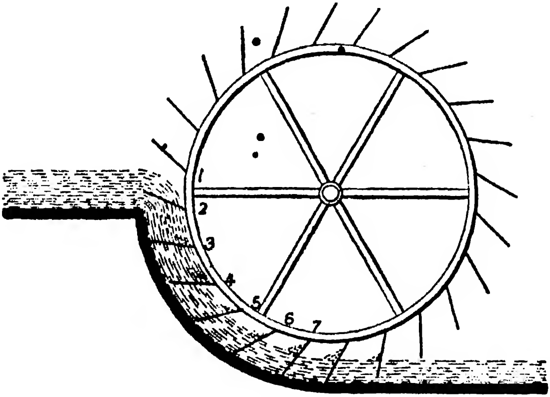

FIG. 65.

Some wheels have shrouds as for overshot wheels, and others work between two walls or similar enclosures, which are so close that very little water can escape past without acting on the wheel. If the buckets are of a good form the water is retained in them until they pass beyond the side walls, whence it flows into the 'tailrace,' or waste water channel.

For calculating the power of a breast wheel

the *weight* of the water and the *impulse* given by its velocity have to be taken into consideration. If the stream enters the wheel at the level of the bucket No. 1, the *weight* has an effect on all the buckets from 1 to 7. If the water level was lowered to bucket No. 2, the power would be less, as only Nos. 2 to 7 would be influenced. And so on until the stream was level with Nos. 6 and 7, when weight would cease to act and impulse only would have any effect.

The velocity of the stream should be such as to give a good impetus to the wheel and exceed the speed of the latter. That is, if the bucket rim travels at the rate of 3 ft. per second the water should flow with a speed of about three times that, or 9 ft. per second. If the wheel and water both travelled at the same speed the power would be wasted, but when the wheel travels at a lower speed it offers a resistance to the water, and it is in pushing that resistance before it that we get what we call 'power' out of the water, and transfer it to the machinery which is to be put in motion. If the wheel was so fitted that no water could escape past without doing duty, to get the full effect the water should enter at about 9 ft. per second, and leave at the velocity of the rim speed of the wheel, or 3 ft. per second, and then flow freely away so as not to drown the floats or buckets by back-water.

If the surface level of the approaching water was even with the axle of the wheel, but there was a sloping fall, as shown by Fig. 66, so that the water strikes bucket No. 2, instead of No. 1, as in Fig. 65, the wheel is more powerful, as the impulse is greater, owing to the extra velocity at-

tained by the water falling from a greater height. The fall may be only a few inches, but with a large wheel this may represent an increase of one or more h.p. By the same reasoning, if the level of the feed water was raised so that it impinged, or fell, on the bucket No. 1, instead of gliding into it, the power would be still more increased.

If the water travels in a straight line level with the centre bucket, as shown by Fig. 65, a great

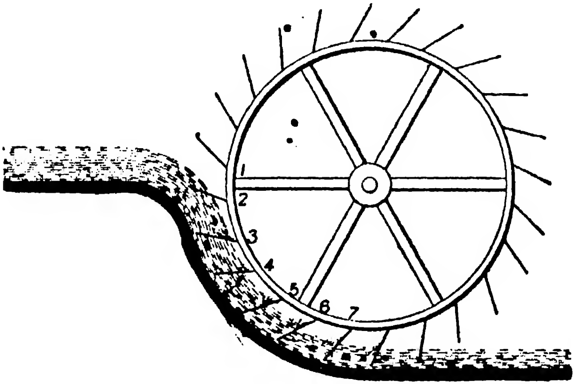

FIG. 66.

deal of the force is expended in knocking against the sole or bottom of the bucket. If the approach is as shown by Fig. 66, the impetus is directed on to the float, or division between the buckets, and the speed of the water is increased by the extra distance fallen. From this we glean that the same quantity of water will, in the latter case, exert a greater power and enter the wheel in a thinner or shallower stream. If the velocity in the feed trough is, say

$4\frac{1}{2}$ ft. per second, and at the moment of striking the float double that, or 9 ft., the thickness of the stream would be about one-half at the moment of impact. . . .

To estimate the power of a breast wheel we first find the contents of the buckets, the quantity of water used, and the height from which it falls. Assuming a wheel is 6 ft. in diameter, the buckets 1 ft. long and 9 in. deep, and the rim velocity 3 ft. per second, the mean diameter, measured in the centre of the buckets would be 5 ft. 3 in., and the circumference at that part 5 ft. 3 in. or 5·25 ft. × 3·1416 = 16·5 ft. The approximate contents if filled with water would be 16·5 × 1 ft. × ·75 ft. = 12·375 cubic feet, or 773 lbs. . .

The rim velocity being 3 ft. per second the wheel revolves 6·28 times per minute, and 773 × 6·28 = 4854·44, to which add 1-4th as an allowance for waste equals 4854·44 + 1213·61 = 6068 lbs. of water per minute required to work the wheel under the given conditions as to speed.

The total height the water falls may be taken from the surface in the channel, measured a short distance back from the outlet or mouth to the bottom edge of the wheel, or say 3 ft. The net quantity of water utilised being 4854 lbs., which × 3 $= 14{,}562$ foot-pounds or $\frac{14{,}562}{33{,}000} = \cdot 44$ h.p. as the estimated power of the wheel. From this should be deducted an allowance for friction and excess of power over load, which for approximation we may take as 1-3rd. Then $14{,}562 \div 3 = 4654$ and $14{,}562 - 4654 = 9708$ or $\frac{9708}{33{,}000} = \cdot 294$ net. h.p.

The power transferred to the pump can be found in nearly the same manner as for the overshot wheel. The diameter being 6 ft., the radius is 3 ft. The weight of water is about that contained in one quarter of the wheel, as will be seen on reference to Fig. 65. The whole of the buckets, if filled, have already been found to contain 12·375 cubic feet, which $\div 4 = 3{\cdot}093$, or say 3 cubic feet, or 187·5 lbs. in one quarter of the wheel. For an approximation we may take it that the weight hangs halfway on a horizontal line drawn from the axis to the outer rim, or at a distance of 18 in. from the axle.

For finding the diameter of the pump the wheel would work

$$\sqrt{\frac{W \times L}{C \times {\cdot}34 \times H}}$$

In which W = weight on wheel in lbs.
L = distance of weight from axis in inches.
C = length of crank, say 4 in.
·34 = weight of water in 1 ft. of 1 in. pipe.
H = height the water is to be raised in feet.
D = diameter of barrel in inches.

$$\text{Then } D = \sqrt{\frac{187{\cdot}5 \times 18}{4 \times {\cdot}34 \times 50}} = \frac{67{\cdot}5}{1{\cdot}36} = 49{\cdot}6$$

and $\sqrt{49{\cdot}6} = 7{\cdot}04$, or say 7 in. the diameter of the barrel.

The actual working size of the pump should be less than this, as such wheels never develop their full working power.

To find the quantity of water that the pump would raise in a given time the rule is :—

$$Q = D^2 \times S \times \cdot 034 \times N,$$

In which D = the diameter of the pump in inches.
S = the length of stroke in feet.
·034 = gallons in 1 ft. of 1 in. pipe.
N = number of strokes per minute.

Then $Q = 7^2 \times \cdot 66 \times \cdot 034 \times 6 \cdot 28 = 6 \cdot 9$ gals. per minute, or 414 gals. per hour.

For percentage of work done by the wheel :

The contents if all the buckets were filled we found to be 12·375 cubic feet, and as they are filled 6·28 times per minute, we have $12 \cdot 375 \times 6 \cdot 28 \times 6 \cdot 25 \times 3 = 1457 \cdot 15$ foot-gallons.

And $6 \cdot 9 \times 50 = 345$ foot-gallons raised.

$\therefore 1457 \cdot 15 : 100 :: 345 : 23 \cdot 68$ nearly.

As the wheel is lifting the water in the pump during only one half of its revolution it follows that half the power is wasted. This wasted power could be utilised, and twice the quantity of water raised, by using a double-barrel or a double-action pump.

Compared with an overshot, a breast wheel is generally assumed to have about $\frac{5}{6}$ths the power, but a great deal depends upon the height to which it is loaded.

CHAPTER XV

UNDERSHOT WHEELS

WHEN the water runs beneath the wheel, and acts by impulse only, it is known as an 'undershot' wheel, and its power is usually considered to be half that of an overshot. Undershot wheels can be fixed in streams and be turned by the current. Where large volumes of water are available, but the streams are shallow, or have

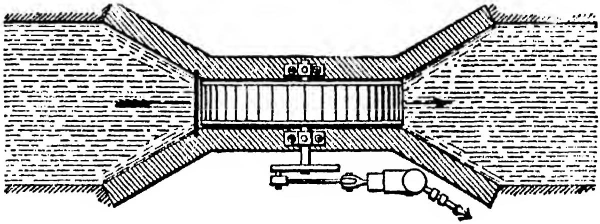

FIG. 67.

very little fall, they are frequently used for pumping water, although they are what may be termed extravagant in the quantity utilised for power.

Where the stream for turning an undershot wheel is wide and shallow, the water should be brought together into a compact current by means of walls, embankments, or other enclosing boundaries, as shown by Fig. 67. Or if the whole of the

water is unnecessary for working it, the wheel can be fixed in a side stream, as Fig. 68. The latter position is the best, as by dropping the sluice at A the wheel B can be thrown out of use when desired. C is a weir for damming back the water for obtaining a 'head.' A further advantage of this arrangement is, that where the stream is affected by storms the excess of water can flow

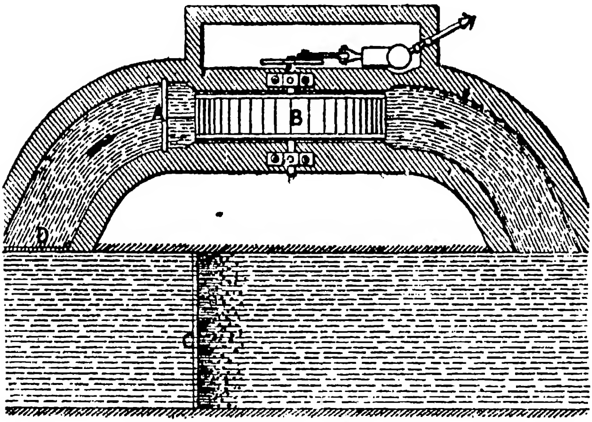

Fig. 68.

over the weir without affecting the wheel. At D is an iron strainer for intercepting floating matters which would clog the wheel.

Many wheels have the 'floats' radiating from the periphery, or the flat rim, in the same lines that the spokes radiate from the axis, but it is doubtful if this is the best method to adopt. When the floats are rising, on the side opposite to the current, they sometimes 'pick up' a portion

of the water, and the weight of this detracts from the power of the wheel. When the floats are of the form shown in the breast wheel, Fig. 65, the water is not carried up to such a great extent.

With what may be called right-angle floats the water strikes against them with a shock, rises up a short distance by momentum, and adds slightly to the head. But this extra head is not all gain, as a portion of the power is expended in raising the water to the higher level. This may be only two or three inches, but it is still a slight waste of the power, although to a certain extent compensated by the after downward pressure. With the floats as Figs. 65 and 66 the water glides in and 'clings' to the wheel for a longer time, or until the float has risen clear of the tail water, and by this action more of the force is utilised.

For calculating the power of a water current it is necessary to first find the velocity. This is best done by placing a weighted float, so that the bottom as well as the surface velocity of flow can be measured, and by noting the time the float takes to travel a given distance, such as between two stakes, a measured distance apart, driven into the bed of the stream in a line with the current. The quantity of water passing can then be calculated from measurements taken of the depth and width of the stream, and then making allowances for alteration in depth and speed as it approaches the wheel.

With an undershot wheel the water presses against the floats, and the pressure multiplied by the area of the surface pressed against equals one factor for calculating the power.

The rule for finding the velocity of falling

bodies is applicable to this case, and is as follows :—

The square root of the height fallen in feet $\times 8 =$ *velocity in feet per second.*

Or, if we know the velocity, to find the height fallen :—*Divide the velocity by* 8 *and square the result*, which gives the answer in feet.

Example : If the water has a velocity of 8 ft. per second, then $8 \div 8 = 1$, and $1^2 = 1$ foot, the head to create the given velocity. Or if the head is 4 ft. then $\sqrt{4} = 2$, and $2 \times 8 = 16$ ft., the theoretical velocity in feet per second.

A cubic foot of water weighs $62\frac{1}{2}$ lbs., and exerts that pressure on each foot of surface exposed to it for every foot of head, and in a stream resists an equal pressure behind it, being itself pushed against.

In practice the floats of an undershot wheel should not be totally immersed, or the back-water would react against them and retard their movement. And neither should they be so deep as to dash against the water as they enter the current.

When calculating the power of an undershot wheel the pressure against the first float, which is totally immersed in the current, only is used. To feed the water to the best advantage a sluice should be fixed for the water to pass beneath and strike the floats when they are approaching the position immediately under the axle. If the sluice is opened so that the water passing beneath is 6 in. deep, and is travelling at the rate of 8 ft. per second, then the head must be 1 ft. to get that speed. The head is measured from the surface of the water on the upper side of the sluice to the

middle of the opening of the latter, so that the actual depth of the higher water is 15 in.

To work out the power of an undershot wheel assume a small one 5 ft. in diameter, or 4 ft. 4 in. as a mean when measured between the floats at half their depths, and having shrouds or sides 1 ft. apart. If the velocity of the water is 8 ft., that of the wheel should be about 1-3rd of that, or say 2·66 ft. per second.

The mean diameter of the wheel being 4 ft. 4 in., then 4 ft. 4 in. or say $4·33 \times 3·1416 = 13·6 =$ the mean circumference. And $\frac{8 \times 60}{13·6 \times 3} = 11·76$ revolutions the wheels should make per minute. Such a wheel would have about 27 floats and $11·76 \times 27 = 317·5$, or say 317 floats would be exposed to the action of the water in one minute. Then $60 \div 317 = 0·19$ nearly of a second each float is acted upon.

The stream being 1 ft. wide $\times$ 6 in. deep, and the water travelling at the rate of 8 ft. per second, this $=4$ cubic ft., which $\times 62\frac{1}{2} = 250$ lbs. of water passing under the sluice per second. Then 19-100th of $250 = 47·5$ lbs. of power exerted on each float as it becomes exposed to the full influence of the water. But the full force is not utilised owing to the wheel being in motion and not at rest. The water travelling at the rate of 8 ft. and the wheel 1-3rd of that, or 2·66 per second, the speed of the former is as 2 is to 1 for the latter. And we may assume that only 2-3rds of the power is utilised. Then 2-3rds of $47·5 = 31·66$ lbs. as the actual water power acting on the wheel in the same manner as one or two men would when working at a winch.

The mean distance of the floats from the axle of the wheel being $30 - 4 = 26$ in. and $31{\cdot}66$ lbs. $\times 26$ in. $= 823{\cdot}16$ inch-lbs. acting on the axle to turn it round. If 1-3rd of this power is absorbed by friction, and as an allowance for power in excess of load, then 2-3rds of $823{\cdot}16 = 548{\cdot}77$, or say 548 inch-lbs., as being the effective power exercised by the wheel.

To find the diameter of the pump that such a wheel would work, it is first necessary to know to what height the water is to be raised and also the length of the stroke, from which to find the length of the crank.

Assuming these to be 80 ft. and 5 in. respectively, then the diameter of the pump $=$

$$\sqrt{\frac{548}{{\cdot}34 \times 80 \times 2{\cdot}5}} = 8 \text{ and } \sqrt{8} = 2{\cdot}8 \text{ in.}$$

As very few surface streams can be depended upon to give a constant and regular supply, the size of the pump should not be calculated on the maximum but on the minimum flow, or when the stream yields the lowest quantity of water. In many cases the above size for the pump should be 2 in., and in others only $1\frac{1}{2}$ in.

In the above calculations no allowance was made for friction of the water flowing in the channel, nor for the water which passed the wheel without doing duty and which cannot be avoided, no matter how well the wheel fits the race or enclosing walls.

The quantities of water that can be raised by pumps when working under various conditions have been before worked out, but for the sake of the practice we will deal with the one above, but assume it is 2 in. in diameter.

The pump having a 2 in. barrel with 5 in. stroke, and worked at the rate of 11·76 strokes per minute, then $2^2 \times {\cdot}034 \times {\cdot}416 \times 11{\cdot}76 = {\cdot}66$ gallons raised per minute, or 39·6 per hour, or 959·4 per day of 24 hours.

The water for turning the wheel being $8 \times 1 \times {\cdot}5 \times 6{\cdot}25 \times 60 = 1500$ gallons per minute and the

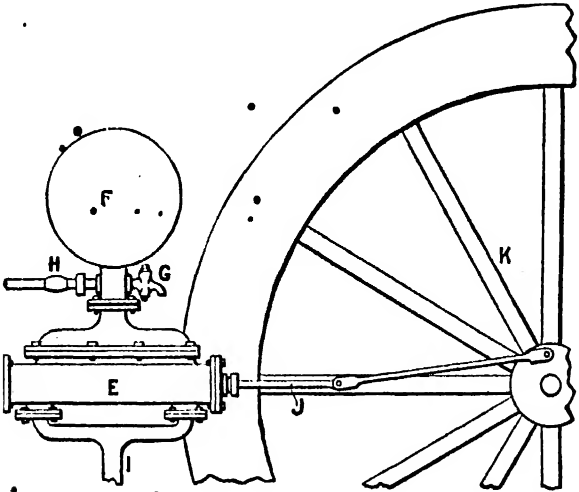

FIG. 69.

quantity raised ·66, the latter is equal to only 1-2272nd part of the whole quantity used.

The same wheel would work a double-action or a double-barrel pump, and thus raise twice the quantity in the same time, or if a treble-barrel pump were used, three times the quantity would be raised with about the same expenditure of power.

As water wheels are usually fixed in valleys, or other positions lower than the houses to be supplied, and frequently a considerable distance away, good size air vessels and small emptying cocks should be fixed on the delivery pipes as close to the pumps as possible.

One form of a double-action pump and connection to the wheel is shown by Fig. 69, in which E is the pump, F the air vessel, G the emptying cock, H the delivery pipe, I the suction pipe, J the plunger rod worked between guides, and K the wheel.

The power of an undershot is generally assumed to be about half that of an overshot wheel.

In most places wheels are used for pumping a portion of the water which drives them, but many streams are totally unfit for domestic use, or for drinking. In such cases the unsuitable water can be utilised for turning a wheel, and a pump or pumps, attached to the latter, can be made to raise water from a small spring, or well, which is pure and available.

Having dealt in an elementary manner with water wheels, we can now pass on to other methods of raising water.

CHAPTER XVI

Chain Pumps

A chain pump consists of a barrel which is parallel from the spout to the bottom, the latter being bell-mouthed, and an endless chain or short rods jointed together, on which discs of wood or iron are fixed at intervals. Over the top of the pump a wheel is fixed, as shown at L, Fig. 70. This is turned by a crank handle, or winch, M. The discs fit the barrel loosely, or not so tight as to cause excessive friction, which would make the pump difficult to work. The bottom of the barrel is immersed in the liquid to be pumped so that it is filled for some distance. On turning the handle the liquid is carried up by the discs, when more liquid runs into the pipe, to be again taken up by the following discs. Some pumps have a hood over the top and the upper portion of the return chain enclosed in a tube, as shown by the dotted lines. Chain pumps are used principally for emptying cesspools, or pumping water with which mud and sand is mixed.

The pumps have flanged bases for fixing on planks, and the spout should be high enough for discharging into mud, or nightsoil, carts. Although usually made of iron, the barrel being round in section, contractors sometimes make them square

in section of boards nailed together, and square wooden discs are used. The iron pumps, 3 in. in diameter, are worked by hand, but large size contractors' pumps are sometimes turned by steam engines. Chain pumps are not suitable for raising water to great heights, and neither should they be worked at a very low speed as the amount of 'slip' is considerable.

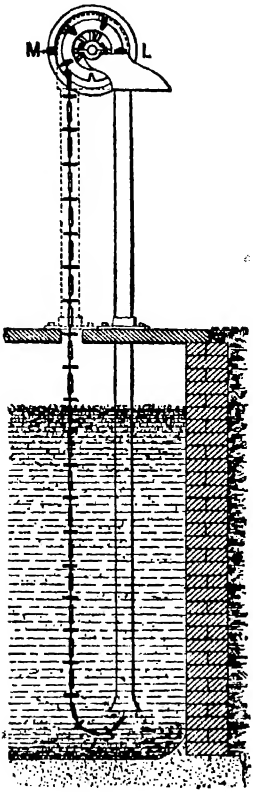

FIG. 70.

With regard to the power to work chain pumps assume, as an example, that the spout is 10 ft. above the surface of the liquid in the cesspool or sump, and the pump has a 3 in. barrel. After turning the handle a few times until the barrel is filled there is a column of liquid 3 in. in diameter and 10 ft. long. This liquid would probably be heavier than water, and if we assume that a cubic foot weighed 66 lbs., then the weight to be lifted would be :—

$$\frac{3^2 \times \cdot 7854 \times 66 \times 10}{144} = 32 \cdot 39 \text{ lbs.}$$

If the wheel which supported and turned the disc chain was 12 in. in diameter, the weight of the contents of the barrel would be suspended at a distance of 6 in. from the centre of the axle. And $32{\cdot}39 \times 6$ in. $= 194{\cdot}34$ inch-lbs. of resistance to be overcome. To this should be added an allowance for friction (which varies with the matter being lifted) and excess of power over load. If we assume that these combined just doubled the load, then the power to raise it should be not less than $196{\cdot}34 \times 2 = 388{\cdot}68$ inch-lbs. If the winch handle is 18 in. long, then $388{\cdot}68 \div 18 = 21{\cdot}6$ nearly lbs. of power to be applied to the handle to work the pump with useful effect.

The quantity of liquid raised by these pumps is governed by the speed at which they are worked. An ample allowance should be made for slip, or water escaping past the discs.

If the wheel is 1 ft. in diameter, and turned at the rate of 25 times per minute, then $1 \times 3{\cdot}1416 \times 25 = 78{\cdot}54$ ft., which equals the length of a column of liquid 3 in. in diameter raised per minute.

And $3^2 \times {\cdot}034 \times 78{\cdot}54 = 24$ gallons. From this should be deducted, say, $\frac{1}{6}$th for slip, and $24 \div 6 = 4$ and $24 - 4 = 20$ gallons, the actual quantity raised in the given time.

Although not usually done so in practice, the chain pump could be utilised as a power for moving machinery in much the same way as by a water wheel. If the head of the pump shown by Fig. 70 was enlarged, the spout removed, and a stream of water made to run into the top of the barrel, the weight on the discs would press them down and cause the wheel, L, to revolve and turn

the crank of a pump or any other machinery to which it was geared.

CHAIN OF BUCKETS

Another machine in which the weight of water acts as a motive power is shown by Fig. 71, and is known as a 'chain of buckets.' The principle is somewhat similar to an overshot, or a breast, wheel, in that one side is loaded with water, the weight of which causes the buckets on that side to travel downwards. The bucket chain is mounted on two drums, which have axles through their centres. The top one, N, is geared to any machinery it is desired to turn. Either drum can be used for this, but the upper one is more firmly gripped by the chain than the lower one.

The equation for finding the power of this appliance is :—

$$R \times C = W \times O$$

Where R = the resistance, or load to be lifted.
C = length of crank, or radius of pulley.
W = weight of water in buckets.
D = radius of the chain wheel.

R and W, and C and D, should respectively be in the same terms.

To work out an example, assume that the loaded buckets contain 100 gallons, or 1000 lbs., the wheel is 3 ft. in diameter and the crank 6 in. long: what weight, or resistance, on the crank would balance the loaded buckets?

$$\text{Then } R = \frac{1000 \text{ lbs.} \times 18 \text{ in.}}{6 \text{ in.}} = 3000 \text{ lbs.}$$

If the appliance had to do work and overcome the friction of the moving parts, instead of just balancing the power, about $\frac{1}{3}$rd of R should be deducted.

Then $3000 \div 3 = 1000$ and $3000 - 1000 = 2000$ lbs., representing R, or the load that could be lifted.

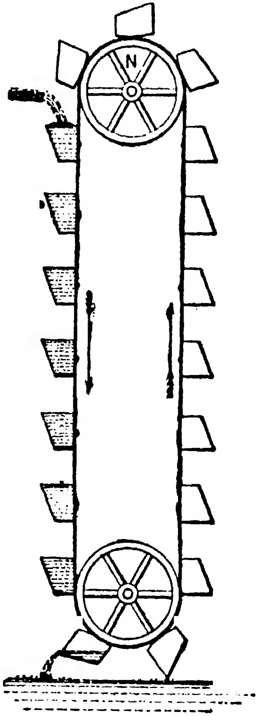

FIG. 71.

The action of the appliance could be reversed, and power applied to the crank or pulley to lift the loaded buckets. Such appliances are used for dredging the beds of rivers and streams, or for hoisting grain and similar matters to higher levels or floors.

To find the power to raise the loaded buckets, using the last values, we have R (or in this case power) $= \frac{1000 \text{ lbs.} \times 18 \text{ in.}}{6 \text{ in.}}$ $= 3000$ lbs. as before. But in this case $\frac{1}{3}$rd should be added to instead of being deducted from the product. Then $3000 + \frac{1}{3}$rd of $3000 = 4000$ lbs. of power to be continuously applied to the crank to lift the loaded buckets.

If we assume that only 1000 lbs. of power are available, but the loaded buckets and diameter of

wheel remain the same, the crank should then be longer. To find the length:

$$C = \frac{1000 \text{ lbs.} \times 18 \text{ in.}}{1000 \text{ lbs.}} = 18 \text{ in.}$$

to just balance the load.

If we again assume that $\frac{1}{3}$rd should be added for reasons before given, then $18 + \frac{1}{3}$rd of $18 =$ 24 in., the length the crank should be to raise the buckets under the given conditions.

CHAPTER XVII

Bucket Wheels

The action of water wheels, too, is sometimes reversed, and power applied by means of a rigger or a crank attached to the axle, to raise water by the buckets or floats. Many examples of these wheels are found in the fens of Lincolnshire for draining the low-lying lands into the main drains, which are at higher levels.

Although these appliances do not come under the heading of plumbers' work, a problem can be taken with the object of illustrating the principles.

For draining the land, subsoil drains made of agricultural pipes—in many cases brushwood, or faggots of wood, are used instead of pipes—are laid to discharge into 'dykes' or open ditches, which run round the fields and thence into main dykes which are dug with a fall towards a point near the high-level main drain, or 'Delph.' Here buildings are constructed and powerful engines fixed for working the wheels or water elevators.

These wheels are fixed between walls, as shown by Fig. 72. In the drawing, O is the water in the main drain, and P that in the main dyke which is at a lower level. Q is the wheel turned by shafting and gearing in connection with a steam engine.

At R is a pair of doors or 'gates,' similar to lock gates, hung on hinges attached to the side walls so as to open outwards into the main drain. The gates are shown opened back into recesses. The dotted lines show them closed. When the wheel is worked and the water is being lifted above that in the main drain, the pressure of the water forces the gates open, but they immediately close by the back pressure when the wheel is stopped or ceases to raise the low-level water.

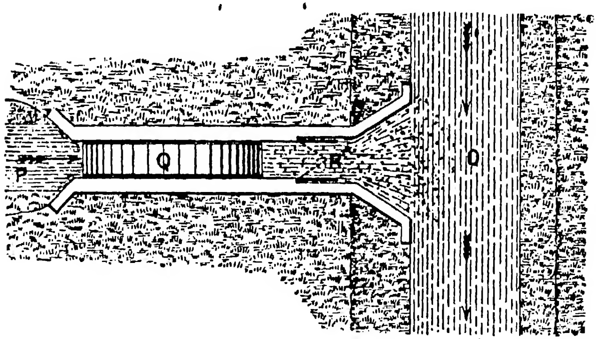

FIG. 72.

The water lift, or difference of level between the high and low streams, is only a few feet, as shown by the sectional drawing, Fig. 73, in which the same reference letters are used as in Fig. 72.

If we assume the case of a wheel which has to raise water to a level 5 ft. higher than the dyke, at the rate of 100,000 gallons per hour, the floats being 1 ft. deep, the wheel's diameter 12 ft., and revolving five times per minute, to find the proper width for the wheel proceed as follows:

Although 100,000 gallons have to be raised the wheel must be capable of raising that quantity plus that which escapes back, owing to the difficulty of constructing the enclosing walls so that there shall be no waste. This quantity varies very much, but if we assume it to be 1-5th of the total, we then have $100{,}000 + \frac{100{,}000}{5} = 120{,}000$ gallons in all, and the wheel should be capable of raising that quantity in the given time, although only 100,000 are actually lifted or delivered into the main drain.

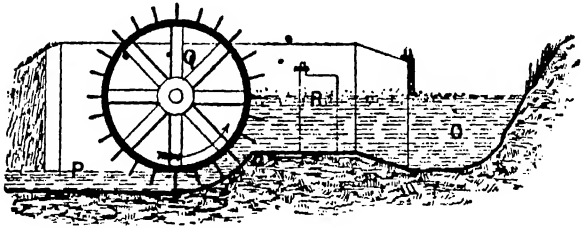

FIG. 73.

Now proceed to find what a wheel 1 ft. wide would do, and from that find the actual width required.

For the contents of the buckets, or the quantity they hold, the simplest method will be to first find how much the wheel would hold when considered as a cylinder, and then deduct the centre portion.

Then $12^2 \times 4{\cdot}9 = 705{\cdot}6$ gallons in the whole wheel.

And $10^2 \times 4{\cdot}9 = 490{\cdot}0$ gallons in the centre of the wheel.

$\therefore 705{\cdot}6 - 490{\cdot}0 = 215{\cdot}6$ gallons in the periphery of the wheel if it was filled.

The wheel has 24 floats, and these being 1 ft. × 1 ft. × $1\frac{1}{2}$ in. thick = 3 cubic feet of space are occupied by them. Then $3 \times 6{\cdot}5 = 18{\cdot}75$ gallons to be deducted from the total quantity, and $215{\cdot}6 - 18{\cdot}75 = 196{\cdot}85$ gallons, the net contents of the buckets. As 1-5th of the water escapes back, then the contents of the buckets should be equal to—

$$\left(\frac{196{\cdot}85 \times 5}{4}\right) = 246 \text{ gals.}$$

The wheel revolves 5 times per minute and $246 \times 5 \times 60 = 73{,}800$ gallons, the gross quantity raised per hour with a wheel one foot wide.

Then $\frac{120{,}000}{73{,}800} = 1{\cdot}627$ ft., or 1 ft. $7\frac{1}{2}$ in., the width of the wheel necessary to raise the given quantity of water per hour under the assumed conditions.

The h.-p. of the engine necessary to work the above wheel, assuming one h.-p. to be equal to 33,000 lbs. raised one foot high in one minute, would be:

$$\frac{120{,}000 \text{ gallons} \times 10 \text{ lbs.} \times 5 \text{ ft.}}{33{,}000 \text{ ft.-lbs. per minute} \times 60 \text{ minutes}} = 3 \text{ h.-p.}$$

to which should be added $\frac{1}{3}$rd for overcoming friction and excess of power over load = 4 h.-p.

In practice, an engine double this, or say 8 h.-p., would be necessary, as an allowance for contingencies during the time of heavy floods.

This has been only a very elementary problem,

but it has served to further elucidate the power of water wheels and the resistance which has to be overcome when raising water to higher levels.

The theory and practice of pumps and their working has now been considered in all its bearings, so far as plumbers are interested, and I hope I have made myself clear in the details.

A great deal more could be said and written about them, but it is doubtful if any advantage would be gained by continuing this branch of our subject.

Appended are tables, for reference by practical men, of sizes of pumps and the theoretical quantity of water that they will raise. Also of pressures to be overcome when raising water by pumping to any height within the scope of ordinary practice.

EASY RULES FOR FINDING APPROXIMATELY THE QUANTITY IN GALLONS DISCHARGED BY PUMPS PER HOUR

SINGLE PUMPS

Worked at 20 strokes per minute.

Diameter²	by	20·4	for	6 in.	stroke.
,,	,,	27·2	,,	8 in.	,,
,,	,,	30·6	,,	9 in.	,,
,,	,,	34·0	,,	10 in.	,,
,,	,,	40·8	,,	12 in.	,,

Worked at 25 strokes per minute.

Diameter²	by	25·5	for	6 in.	stroke.
,,	,,	34·0	,,	8 in.	,,
,,	,,	38·25	,,	9 in.	,,
,,	,,	42·5	,,	10 in.	,,
,,	,,	51·0	,,	12 in.	,,

Double Pumps

Worked at 20 strokes per minute.

Diameter^2	by	40·8	for	6 in.	stroke.
,,	,,	54·4	,,	8 in.	,,
,,	,,	61·2	,,	9 in.	,,
,,	,,	68·0	,,	10 in.	,,
,,	,,	81·6	,,	12 in.	,,

Worked at 25 strokes per minute

Diameter^2	by	51·0	for	6 in.	stroke.
,,	,,	68·0	,,	8 in.	,,
,,	,,	76·5	,,	9 in.	,,
,,	,,	85·0	,,	10 in.	,,
,,	,,	102·0	,,	12 in.	,,

Treble Pumps.

Worked at 20 strokes per minute.

Diameter^2	by	61·2	for	6 in.	stroke.
,,	,,	81·6	,,	8 in.	,,
,,	,,	91·8	,,	9 in.	,,
,,	,,	102·0	,,	10 in.	,,
,,	,,	122·4	,,	12 in.	,,

Worked at 25 strokes per minute.

Diameter^2	by	76·5	for	6 in.	stroke.
,,	,,	102·0	,,	8 in.	,,
,,	,,	114·75	,,	9 in.	,,
,,	,,	127·5	,,	10 in.	,,
,,	,,	153·0	,,	12 in.	,,

The following tables are based on the foregoing rules.

TABLE I

SINGLE PUMPS.—Worked at 20 strokes per minute.

Diameter in inches	Gallons raised per hour				
	6 in. stroke	8 in. stroke	9 in. stroke	10 in. stroke	12 in. stroke
2	81	102	122	136	163
2½	127	170	191	212	255
3	183	244	275	306	367
3½	250	333	374	416	499
4	326	435	489	544	652
4½	413	550	619	688	826
5	510	680	765	850	1020
6	734	979	1101	1224	1468
7	999	1332	1499	1666	1999
8	1305	1740	1958	2176	2611
9	1652	2203	2478	2754	3304
10	2040	2720	3060	3400	4080
12	2937	3916	4406	4896	5875

TABLE II

SINGLE PUMPS.—Worked at 25 strokes per minute.

Diameter in inches.	Gallons raised per hour				
	6 in. stroke	8 in. stroke	9 in. stroke	10 in. stroke	12 in. stroke
2	102	136	153	170	204
2½	159	212	239	265	318
3	229	306	344	382	459
3½	312	416	468	520	624
4	408	544	612	680	816
4½	516	688	774	860	1032
5	637	850	956	1062	1275
6	918	1224	1377	1530	1836
7	1249	1666	1874	2082	2499
8	1632	2176	2448	2720	3264
9	2065	2754	3098	3442	4131
10	2550	3400	3825	4250	5100
12	3672	4896	5508	6120	7344

NOTE.—These tables also give the theoretical quantity raised by a double-barrel pump with wheel and pinion motion geared 2 to 1, or a treble-barrel pump geared 3 to 1, when the crank shaft revolves 20 and 25 times per minute.

TABLE III

Double Pumps

Worked at 20 strokes per minute.

Diameter in inches	Gallons raised per hour				
	6 in. stroke	8 in. stroke	9 in. stroke	10 in. stroke	12 in. stroke
2	163	216	244	272	326
2½	255	340	382	424	510
3	367	488	550	612	734
3½	499	666	748	832	998
4	652	870	978	1088	1304
4½	826	1100	1238	1376	1652
5	1020	1360	1530	1700	2040
6	1468	1958	2202	2448	2936
7	1999	2664	2998	3332	3998
8	2611	3480	3916	4352	5222
9	3304	4406	4956	5508	6608
10	4080	5440	6120	6800	8160
12	5875	7832	8812	9792	11750

TABLE IV

Double Pumps

Worked at 25 strokes per minute.

Diameter in inches	Gallons raised per hour				
	6 in. stroke	8 in. stroke	9 in. stroke	10 in. stroke	12 in. stroke
2	204	272	306	340	408
2½	318	424	478	530	637
3	459	612	688	764	918
3½	624	832	936	1040	1258
4	816	1088	1224	1360	1632
4½	1032	1376	1548	1720	2065
5	1275	1710	1912	2124	2550
6	1836	2448	2754	3060	3672
7	2499	3332	3748	4165	4998
8	3264	4352	4896	5440	6528
9	4131	5508	6196	6884	8262
10	5100	6800	7650	8500	10200
12	7344	9792	11016	12240	14688

TABLE V

Treble Pumps

Worked at 20 strokes per minute.

Diameter in inches	Gallons raised per hour				
	6 in. stroke	8 in. stroke	9 in. stroke	10 in. stroke	12 in. stroke
2	244	326	367	408	489
2½	382	510	573	637	765
3	540	734	826	918	1101
3½	749	999	1124	1249	1499
4	979	1395	1468	1632	1958
4½	1239	1652	1858	2065	2478
5	1530	2040	2295	2550	3060
6	2203	2937	3244	3672	4406
7	2998	3998	4498	4998	5996
8	3916	5222	5875	6528	7833
9	4957	6669	7435	8262	9914
10	6120	8160	9180	10200	12240
12	8812	11750	13219	14688	17625

TABLE VI

Treble Pumps

Worked at 25 strokes per minute.

Diameter in inches	Gallons raised per hour				
	6 in. stroke	8 in. stroke	9 in. stroke	10 in. stroke	12 in. stroke
2	306	408	459	510	612
2½	477	636	717	796	954
3	688	918	1032	1147	1377
3½	937	1249	1405	1561	1874
4	1224	1632	1836	2040	2448
4½	1549	2065	2323	2581	3098
5	1912	2550	2868	3187	3825
6	2754	3672	4131	4590	5508
7	3748	4998	5622	6247	7497
8	4896	6528	7344	8160	9792
9	6196	8262	9294	10327	12393
10	7650	10200	11475	12750	15300
12	11016	14688	16524	18360	22032

TABLE VII

Pressure in lbs. to be overcome in raising water by pumping from 10 to 200 ft. perpendicular, measured from surface of water in well or reservoir to delivery tank.

Rule.—Diameter in inches squared × ·34 for each foot vertical height.

Height in feet	Diameters of barrels: 2	2½	3	3½	4	4½	5	6	7	8	9	10	12	Height in feet
10	13·6	21·2	30·6	41·6	54·4	68·8	85·0	122·4	166·6	217·6	275·4	340·0	489·6	10
20	27·2	42·5	61·2	83·3	108·8	137·7	170·0	244·8	333·2	435·2	550·8	680·0	979·2	20
30	40·8	63·7	91·8	124·9	163·2	206·5	255·0	367·2	499·8	652·8	826·2	1020·0	1468·8	30
40	54·4	85·0	122·4	166·6	217·2	275·4	340·0	489·6	666·4	870·4	1101·6	1360·0	1958·4	40
50	68·0	106·2	153·0	208·2	272·0	344·2	425·0	612·0	833·0	1088·0	1377·0	1700·0	2448·0	50
60	81·6	127·5	183·6	249·9	326·4	413·1	510·0	734·4	999·6	1305·6	1652·4	2040·0	2937·6	60
70	95·2	148·7	214·2	291·5	380·8	481·9	595·0	856·8	1166·2	1523·2	1927·8	2380·0	3427·2	70
80	108·8	170·0	244·8	333·2	435·2	550·8	680·0	979·2	1332·8	1740·8	2203·2	2720·0	3916·8	80
90	122·4	191·2	275·4	374·8	489·6	619·6	765·0	1101·6	1499·4	1858·4	2478·6	3060·0	4406·4	90
100	136·0	212·5	306·0	416·5	544·0	688·5	850·0	1224·0	1666·0	2176·0	2754·0	3400·0	4896·0	100
110	149·6	233·7	336·6	458·1	598·4	757·3	935·0	1346·4	1832·6	2393·6	3029·4	3740·0	5385·6	110
120	163·2	255·0	367·2	499·8	652·8	826·2	1020·0	1468·8	1999·2	2611·2	3304·8	4080·0	5875·2	120
130	176·8	276·2	397·8	541·4	707·2	895·1	1105·0	1591·2	2165·8	2828·8	3580·2	4420·0	6364·8	130
140	190·4	297·5	428·4	583·1	761·6	963·9	1190·0	1713·6	2332·4	3046·4	3855·6	4760·0	6854·4	140
150	204·0	318·7	459·0	624·7	816·0	1032·8	1275·0	1836·0	2499·0	3264·0	4131·0	5100·0	7344·0	150
160	217·6	340·0	489·6	666·4	870·4	1101·6	1360·0	1958·4	2665·6	3481·6	4406·4	5440·0	7833·6	160
170	231·2	361·2	520·2	708·0	924·8	1170·5	1445·0	2080·8	2832·2	3699·2	4681·8	5780·0	8323·2	170
180	244·8	382·5	550·8	749·7	979·2	1239·3	1530·0	2203·2	2998·8	3916·8	4957·2	6120·0	8812·8	180
190	258·4	403·7	581·4	791·3	1033·6	1308·2	1615·0	2325·6	3165·4	4134·4	5232·6	6460·0	9302·4	190
200	272·0	425·0	612·0	833·0	1088·0	1377·0	1700·0	2448·0	3332·0	4352·0	5508·0	6800·0	9792·0	200

INDEX

Printed by SPOTTISWOODE, BALLANTYNE & Co. LTD.
Colchester, London & Eton, England